ABSORPTION OF SOLAR RADIATION BY WATER IN SOLAR STILLS

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PREFACE

Solar water distillation was known even centuries ago, but low efficiency of the solar water distillation system (Solar Still) has been one of the major problems. Numerous attempts on the improvement/change in design parameters to increase the efficiency have been reported in the literature, however very little has been reported on the liquid collector property of water itself, which has a great potential in the area of solar energy utilisation; specially solar water distillation. The original plan of the present project was to study the "effect of dyes on the performance of the still", but during the course of this work, it was felt that certain other parameters may also lead to improvement in the still performance. Preliminary studies, therefore, were undertaken on these parameters.

A brief account of the work presented in this report is given below;

Chapter I
This chapter gives the background, importance and aims of this project.

Chapter II
The theoretical analysis of the solar still in presence of a dye (black dye) has been presented in this chapter.

Chapter III

The extent of utilisation of solar energy, specially visible portion of the solar spectrum could be increased by mixing a water soluble dye in the brackish water. As many as 14 Organic and 3 Inorganic dyes were studied at different sets of dye concentration/water depths. A number of dyes have been found to be quite effective, eg., blue, green, black, red, etc. Red and green dyes were found to be effective even at very low concentration, viz., 50 ppm. In view of the cost/benefit analysis, 100 ppm concentration was found quite effective.

Chapter IV & Chapter V

Solar distillation being surface phenomenon, the evaporation is expected to increase with the increase in the surface area as well as the difference in temperatures of water and that of the glass cover. The still performance with the following arrangements were studied.

a) Floating Coal) both in presence and
b) Channels) absence of the dye.
c) Stirring of brackish water
d) Bubbling of ambient air
e) Bubbling of dry air
f) Cooling of the glass cover
g) Simultaneous bubbling and cooling of glass cover.

The distillate output was found to increase (compared to reference) in each case except (d).

CHAPTER-I

INTRODUCTION

Summary

A brief account of the background work and importance of solar water distillation/desalination has been given in this chapter.

Among the basic necessities of man, water comes after air and food in priority. The importance of availability of hygienic potable fresh water (i.e. containing less than 500 ppm total dissolved solids) hardly needs any mention. The river, lakes and underground water reservoirs are some of the well known sources of fresh water which have been in use for domestic, agricultural and industrial purposes. However, such sources are not always desirable due to, for instance, high content of dissolved solids or presence of harmful organisms. The impact of many diseases affecting mankind can be reduced if fresh and hygienic water is available for drinking. Rapid industrialization and population growth all around the world are two important factors responsible for such an escalation of demand for fresh water. This as expected is leading to acute shortage of fresh water.

Rivers and lakes are being polluted due to large amounts of input from industrial wastes and sewage. Similarly, leaching of solid wastes dumped in open by rain water leads to pollution of underground water reservoirs (e.g. formation of carcinogen trinitrosoamines due to leaching of fertilizer). In fact on global scale man made pollution of natural source of water is turning out to be the single largest reason for the fresh water shortage, and one of the main factors responsible

for scarcity of fresh water in urban and rural areas. Besides this there are several regions on the earth which have inhospitable climatic conditions and have only brackish water sources. In such places fresh water needs are to be met not only for domestic but also for agricultural purposes. It is for these reasons the expectations that by end of this century, supply of adequate quantities of fresh and potable water could become one of the most serious problems confronting mankind.

It is estimated that more than 200 million people do not have facility for adequate water supply. It is with this objective that UNO declared 1981-1999 as the International Drinking Water Supply and Sanitation Decade (IDWSSP). The aim of this is to cover at least half of the worlds population by the end of this decade. Developing countries in general and India in particular is giving top priority to rural water supply under its rural development programme. Most of the international organisations like WHO, UNDP and World Bank are financing the projects relating to drinking water supply to Indian villages with special reference to low cost water supply techniques e.g. hand-pumps for ground water pumping. More than a quaber of the UNICEF's assistance has been directed mainly towards supply of safe driniking water.

There are various methods through which pottable water can be obtained. Some of the conventional methods used for desalination of water are:

Multistage fresh water evaporation;

Multi: effect evaporation

Thin film distillation;

Reverse Osmosis; and

Electro dialysis.

However, all these methods are most energy intensive and uneconomical for small scale fresh water demands especially when the cost of fuel is also increasing. Solar water distillation, on the other hand, is one which has been demonstrated to be the most suitable and economic method for distillation, where demands are not too large. Use of solar energy for such purpose becomes more attractive because it has very little recurring expenditure and can be utilized even in remote areas where any other form of energy or process may not be effective. In general solar water distillation is one of the most efficient promising and viable options for providing potable water to smaller communities and also in places where fresh water is required in emergency and other sources of energy are not available.

Historical:

The process of solar water distillation has been known even in ancient times and was used in preparation of perfumes, medicines etc. (Mouchot 1869). The work of Della Porta in as early as 1589 seems to be the oldest known reference in the area of solar desalination (Nebbia & Menozzi 1966). However,

during earlier years of development the work on this aspect was mainly oriented towards its utilization for a particular purpose. For instance, French workers used it for the purpose of supplying fresh water to the colonial troops in French occupied desert regions of North Africa. World's first large distillation set up (still) as described by Harding (1883), was designed and developed by a Swedish engineer Carlos Wilson in 1872 at La-Salinas in Chile. The set up consisted of Wooden bays (1.14 m x 61.6m) having area of about 4700 m^2 and produced a maximum of 5000 gallons per day of distilled water. It is interesting to note that this was one of the oldest stills which was in operation for the longest period of about 40 years i.e. upto the start of first world war. Another worth mentioning fact is that practically no development work was known to have taken place until 1930, when for the first time it became a subject of systematic study. Dr. Maria Talkes (1945) in United States of America did considerable amount of work, during second World War on the development of collapsible solar stills for use of life rafts.

These units consisted of inflatable plastic envelope containing a felt pad and a distillate collector bottle connected to the bottom of theplastic envelope. When in use the pad was to be saturated with the sea along side the raft after inflation.

Later Dr. Telkes also studied the thermodynamics of the process and gave a scientific basis for her own work and for

further development. Several small experimental glass covered stills were later designed and constructed in many countries like USA., USSR., Australia, Italy, Greece etc. An account of solar stills constructed and used in different countries has been given in Table-I.1.

Later a number of different designs of solar stills were developed with a view to increase the performance efficiency of solar stills. Some of these are:

(i) Conventional Solar stills (also known as simple, green house or roof type);

(ii) Inclined tray solar stills,

(iii) Tilted wick type solar still:

(iv) Multiple effect solar still;

(v) Chimney type solar still;

(vi) Heated head or solar collectors supplying heat to solar stills

(vii) Spherical solar stills with wiper; and

(viii) Double Basin still.

[illegible]

There are two important features of a distillation process - a boiler to evaporate the brackish water with the help of a fuel and a separate condenser to cool the vapours into liquid water. In solar stills both these are included in one set up and the source of heat in solar energy instead of any commercial fuel.

Table-I.1

Some solar distillation plants*

Country	Location	Design	Year	m^2	Feed	Cover	Remarks
Australia	Muresk I		1963	372	Brackish	Glass	Rebuilt
	Muresk II		1966	372	Brackish	Glass	Operating
	Coober Pedy	3.1c	1966	3160	Brackish	Glass	Operating
	Caiguna		1966	372	Brackish	Glass	Operating
	Hamalin Pool		1966	557	Brackish	Glass	Operating
	Griffith		1967	413	Brackish	Glass	Operating
Cape Verde Isl	Santa Maria	3.1c	1965	743	Seawater	Plastic	
	Santa Maria		1968				Abandoned
Chile	Las Salinas	3.1c	1872	4460	Brackish	Glass	Abandoned
	Quillagua		1868	100	Seawater	Glass	Operating
Greece	Symi I	3.1d	1964	2686	Seawater	Plastic	Rebuilt
	Symi II	3.1d	1968	2600	Seawater	Str.Plast.	Dismantled
	Aegina I	3.1c	1965	1490	Seawater	Plastic	Rebuilt
	Aegina II	3.1d	1968	1486	Seawater	Str.Plast.	Abandoned
	Salamis	3.1c	1965	388	Seawater	Plastic	Abandoned
	Patmos		1967	8600	Seawater	Glass	Operating
	Kimolos		1968	2508	Seawater	Glass	Operating
	Nisyres	3.1f	1969	2005	Seawater	Glass	Operating
	Fiskardo		1971	2200	Seawater	Glass	Operating
	Kionion		1971	2400	Seawater	Glass	Operating
	Megisti		1973	2528	Seawater	Glass	Operating
India	Bhavnagar	3.1c	1965	377	Seawater	Glass	Operating
	Awania	3.1e	1978	1866	Brackish	Glass	Operating

Country	Location	Design	Year	m^2	Feed	Cover	Remarks
Mexico	Natividad Is1	3.1d	1969	95	Seawater	Glass	Operating
Pakistan	Gwadar I	3.1f	1969	306	Seawater	Glass	Operating
	Gwadar II	3.1g	1972	9072	Sea ater	Glass	Operating
Spain	Las Marinas	3.1a	1966	868	Seawater	Glass	Operating
Tunisia	Chakmou	3.1d	1967	440	Brackish7	Glass	Operating
	Mahdia		1968	1300	Brackish	Glass	Operating
U.S.A.	Daytona Beach	3.1e	1959	228	Seawater	Glass	Rebuilt
	Daytona Beach		1961	246	Seawater	Glass	Dismantled
	Daytona Beach	3.1b	1961	216	Seawater	Plactic	Dismantled
	Daytona Beach		1963	148	Seawater	Plastic	Dismantled
USSR	Bakharden	3.1e	1969	600	Brackish	Glass	Operating
West Indies	Potit St.Vincen	3.1b	1967	1,10	Seawater	Plastic	Operating
	Haiti	3.1b	1969	223	Seawater	Glass	Operating
India	Bitra	3.1c	1980	-	Brackish	Glass	Operating capacity 2000 litre/day
	Kulmis		1980	-	Brackish	Glass	Opdrating capacity 3000 litre/day
China	Wuzhi		1976	385	Seawater	Glass	Operating
	Zhungjian		1979	50	Seawater	Glass	Operating

*After Delyannis and Delyannis (1973).

Solar radiations impinging on the surface of oceans, rivers and lakes are absorbed as heat and causes evaporation of water from their surface, the resulting vapour rises as humidity of the air above the surface and is moved alongwith the wind. As and when the air-vapour mixtures is cooled to the dew-point temperature, condensation may occur, and the water may be precipitated as rain or snow. The essential features of this process are:

(a) production of water vapours above the surface of the liquid

(b) transport of this vapour by air;

(c) cooling of the air-vapour mixture; and

(d) condensation and precipitation.

A similar process occurs in the conventional type solar stills i.e. a layer of brackish water or saline water is introduced into an air tight and water tight basin which is exposed to sun. The basin is covered by a material which serves two major purposes, it prevents escape of humid air above the water surface, and furnishes a cool surface upon which the vapours can condense. In addition this cover also serves as a radiation shield and reduces the energy loss by emitted long-wave radiations from the water surface. While netither the glass nor the sheet plastic material used for the covers are completely transparent to solar radiations, but they absorb and reflect only a small portion of it and interfere very little with the evaporation process. Thus the solar energy trapped in

the still is used to evaporate the water, saturating the air with water vapours and leaving the salt behind. The water vapours condense on the inside of the glass cover, due to increse in humidity (vapour pressure) within the still.

A schematic cross section of this type of solar still is shown in figure :II.1.

The incident radiation are lost through reflection and/or absorption on (a) glass cover; (b) water surface; and (c) bottom of the still.

In addition convection losses occur through the air space between the water surface and the glass cover. Therefore, any measure to reduce these losses will require (i) a thin cover having excellent transparency to solar wavelength; (ii) as much as possible a clear water surface; (iii) a thin air gap space between water surface and the cover; and (iv) a good insulation at the black bottom of the basin. Though a great number of variations in the design of conventional solar still have been reported but the difference have been chiefly in terms of materials used, the geometry of the schemes of supporting and attaching the transparent cover and outlet distilled water (Baum et al., 1970, Cooper 1969, 1973; Delyannis 1973; Frick 1970; Garg et al., 1976; Hirshmann et al., 1970; Sodha et al., 1981 a-c, to mention a few).

Efficiency:

The efficiency of the still depends upon the extent of

utilization of incident solar insolation (radiation) by brackish water and the intensity of incident solar radiations. While the former comes under the pergiew of R & D work, Later, however, is dependent upon nature and varies from place to place and season to season. The efficienty (n), of solar still is defined as the ratio of the solar insolation incident on the still(Qt Joules/m^2 day) and the amount utilized in vaporising the water (Qe,Joules/m^2 day).

$$\text{i.e. } n = \frac{Qe}{Qt} \qquad (1)$$

In equation (1), the quantity Qt can be obtained from the insolation data directly while Qe is determined in the following manner,

The productivity of the still (P, kg/m^2 day) is expressed as the ratio of the energy used for evaporation of the water mass and the Latent heat of water (L = 28.1 Joules/Kg) i.e.

$$P = \frac{Qe}{L} \qquad (2)$$

$$Qe = P \times L \qquad (3)$$

The equation (1) can thus be rewritten as,

$$n = \frac{P \times L}{Qt}$$

or $$P = \frac{n \times Qt}{L}$$

or $$P = 3.55 \times 10^{-2} .n.Qt \qquad (4)$$

i.e. a higher value of efficiency or the incident radiations will produce larger amount of distilled water.

As already mentioned that the insolation is nature dependent, however, an attempt to increase the efficiency of the still could increase the distillate output. This could be achieved either by a change/improvement in the design paramenters of the still and or by increasing the extent of absorption of incident solar radiations by brackish water itself. A literature survey indicated that a lot of work has been done on the former, however, practically no systematic study had been reported on the later aspect prior to this work. It would not be out of place to mentioned that even now, except one recent paper, by Rajvanshi (1981), one three colours, no other study is available other than those published as a part of this project/Sodha et al., 1980, Pandey 1980, 1981, 1982a-c, 1983a-b).

The present project was undertaken with a view to improve the efficiency of the solar distillation plants (still). The different studies undertaken have been given below; (i) Effect of dyes (The extent of utilization of incident solar energy by water itself (instead of black bottom) and relatively higher water depth, increased the thermal storage capacity of the still which also provided distilled water during night (as against shallow water levels used in conventional stills).

14 water soluble organic dyes have been studied, in detail at different sets of water depths and dye concentrations

(Pandey, 1982a). The stability of the dyes, in sunlight has also been studied for periods ranging from a week to a month.

In view of the possible reactivity/instability of the organic dyes in saline water, a preliminary study on a few Inorganic dyes was also undertaken.

2. Seasonal Performance of the Dyes:

Monthly data on the performance of two of the organic dyes - Methylene Blue and Diphenyl Black have been collected for more than a year, inorder to see the variation in the extent of increase in distillate output with season

3. Surface Aréa:

Solar water distillation being a surface evaporation process, it was expected that distillation (evaporation) will depend upon:

(a) large surface area; and

(b) large difference in the temperatures of water and that of the glass cover.

Studies on the performance of the solar stills with,

(i) Floating Coal
(ii) Channels

both in presence and absence of the dyes.

(iii) Stirring of brackish water.

(iv) Bubbling of ambient air.

(v) Bubbling of ambient air after drying

(vi) Simultaneous bubbling of dry air and cooling of glass cover. were undertaken to see the performance of solar still.

4. Double Basin Solar Still :

Performance of the double basin still (Malik 1978) was studied with and without dye. Extent of increase has been reported.

[illegible] s in Solar Still

Hourly data on water temperatures showed relatively a higher value in dye containing brackish water in the evenings which decreased slowly with time and was responsible for distillation during the night (due to thermal storage). Utilization of this stored thermal energy by dye containing brackish water for applications other than distillation (e.g. air/water heating) have been suggested

6. Water Quality of the Distillate Output:

It was suspected that the use of the dye, in solar stills, might contaminate the distilled water produced. In order to ensure the absence of even traces of the dyes, spectroscopic study of the distilled water from solar stills was carried out and compared with that obtained by standard distillation method. Most of the common cations like Na^+, K^+, Ca^{+2}, Mg^{+2} etc were also determined by atomic absorption spectrometer and were found to be negligible. It may be mentioned that the quality of distilled water from the solar still was comparable with that obtained by standard distillation method.

7a. Comparison of data from other laboratories:

One of the organic dyes-Methylene Blue (Commercial grade) was sent to CSMCRI Bhavnagar, for the performance data on one of their laboratory (Small) scale solar stills. Their data showed a good agreement with that of ours. However, the dye was found to be unstable in saline water (i.e. the colour faded

in 5-6 days).

7b. <u>Performance on large Solar Stills</u> :

CSMCRI has installed one large solar water distillation plant at Awania Village in Bhavnagar which supplied potable water to the village inhabitants. 100 ppm of Methylene Blue dye was used in one of the units of this plant (2000 litre capacity) and the distillate output data were recorded - on both the AR grade and commercial grade dyes.

The performance data on these dyes showed: that there was a significant increase in distillate output during the day time (8 A.M. - 6 P.M.) as compared to the reference having black basin. The dye however, was not stable in saline water which is used in their stills.

<u>Studies at Jyoti Ltd. Baroda:</u>

Recently Venkatarman et. al. (1981) have reported their studies on the performance of black dye in a solar Stills, Though they have not mentioned exculusively however, from the paper it seems they have compared the performance of the black dye with the solar still without black basin liner and have found considerable increase. It may be mentioned that the results presented in the present report have been compared with the reference still having black basin liner, in order to show the relative performance the still containing a dye with that of a conventional solar still.

CHAPTER-II

THEORETICAL ANALYSIS OF THE PERFORMANCE OF SOLAR STILL IN PRESENCE OF A DYE

Summary

In this chapter the periodic analysis of a solar still with water- dye system in the basin has been presented. The obsevations for a black dye have been found to be in good agreement with the theory.

In this chapter the theory for the behaviour of the solar still with a dye dissolved in water has been presented. The analysis assumes a large water mass and linearisation of Dunkle's (1961) equation in the range of operating parameters. In the present investigation-unlike the analysis of Rajvanshi (1981), conduction through the insulation has been taken into account and the water has been assumed to be at a uniform temperature. The experimental results corresponding to two identical stills were found to be in good agreement with theory.

At this stage it is interesting to appreciate the physics underlying the enhancement in the output of the distillate by addition of a dye. In a conventional still, most of the solar radiation is absorbed by the bottom, which becomes the hottest region of the still; heat is transferred by the bottom surface to water by convection and to the outside atmosphere by conduction through the insulating layer. When a dye is mixed with water almost all the solar radiation is directly absorbed by the water; the water transfers part of the heat to the bottom, which is conducted to the outside atmosphere, through the insulation. Hence the water in a still (using a dye) is at a higher temperature than that in another still, not using a dye, this accounts for the higher distillate output in the still, using the dye.

ANALYSIS

Fig. II.1 depicts the different heat transfer modes, the energy balance conditions for the glass cover, basin water and absorbing surface can be written as,

$$M_g \frac{dT_g}{dt} = \tau_1 H_s + (Q_{rw} + Q_{cw} + q_{ew}) - Q_a \quad \text{---(1)}$$

$$M_w \frac{dT_w}{dt} = \tau_2 H_s + Q_w - (Q_{rw} + Q_{cw} + Q_{ew}) \quad \text{---(2)}$$

Where, $\tau_3 H_s = Q_w + Q_{ins.}$ ---------(3)

$$\tau_1 = (1-R_g)\,\alpha_g$$
$$\tau_2 = (1-R_g)\,(1-\alpha_g)\cdot\alpha_w \quad \text{----(4)}$$
$$\tau_3 = (1-R_g)\,(1-\alpha_g)\,(1-\alpha_w)\,\alpha_b$$

and $$\alpha_w = \left[\,1 - \exp\left(-m\,\beta_m\,Y\right)\right]$$

The expressions for Qa , Qrw , Qew and Qcw following Dunkle[1961], are given in Appendix-II.1. The following assumptions have been made use of in writing equations (1)-(3)

i) Constant mass of water is maintained by continuous addition of water to keep a constant level in the basin; so that the rate of addition of water is the same as that of evaporation. It is further assumed that the heat required to heat the water from the ambient temperature (before addition to the basin) to the temperature of water in the basin is negligible as compared to that required to evaporate the same mass

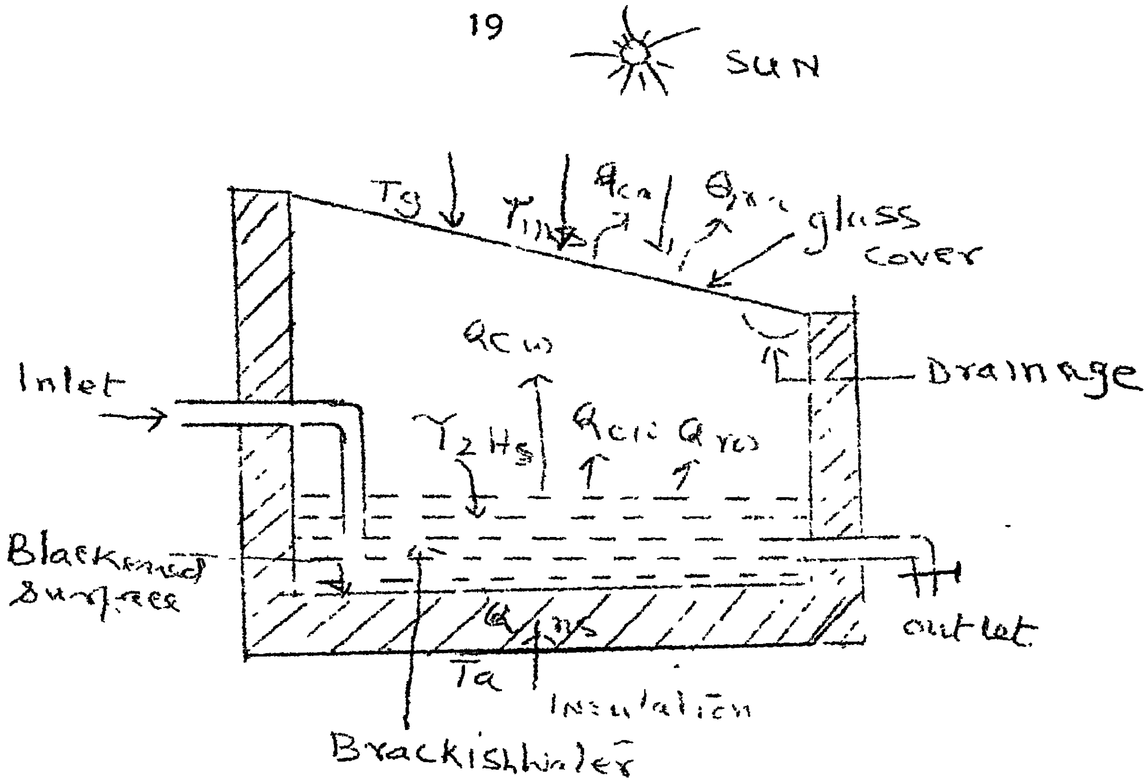


Fig II.1 Schematic Representation of still.

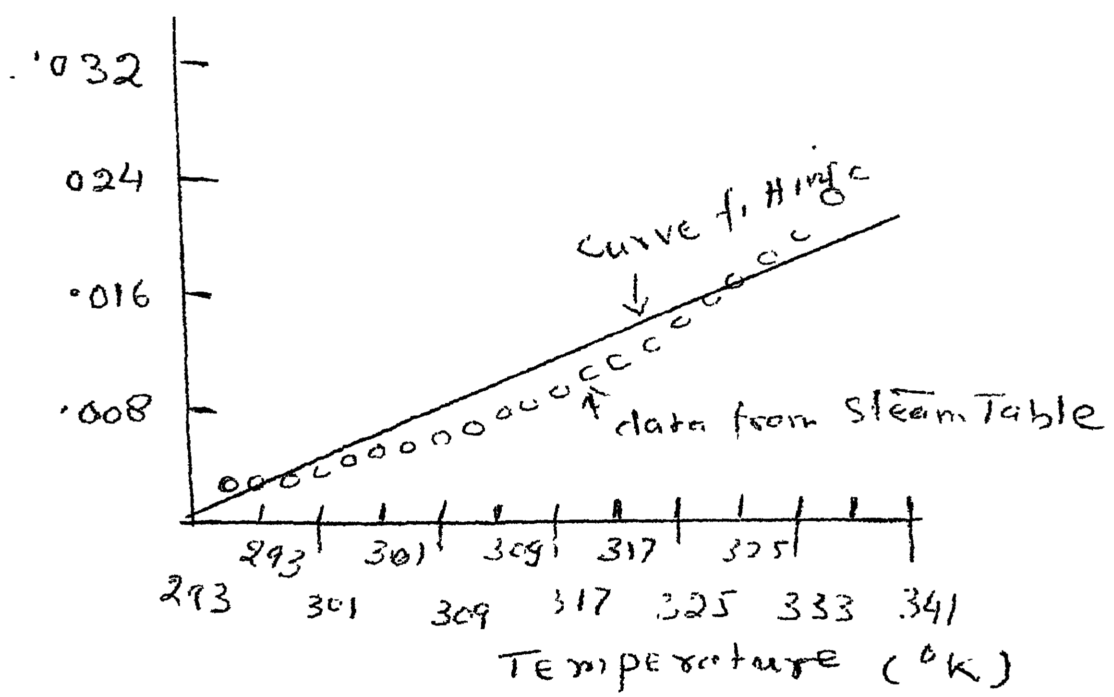


Fig II.2 Variation of the Saturation Vapour pressure with temperature

i.e.

$$C_p\,(T_w - T_a) \ll h_w$$

the above inequality is, in general, reasonably valid.

ii) There is no vapour leakage in the still.

iii) The temperature gradients along the glass cover thickness and water depth has been assumed to be absent.

iv) The area of cover glass, still and surface area of water are considered to be equal.

The observed dependence of the vapour pressure of water on the temperature, to a good approximation can be expressed by the linear relation Sodha et. al. (1978),

$$p = R_1 T + R_2 \tag{5}$$

where R_1 and R_2 possessing the constant values, are to be calculated from the saturation vapour pressure data by least square curve fitting in the temperature range of interest.

The energy transferred from the absorbing surface to the water and vice-versa (water with dye) can be written respectively as

$$q_W = h_3\,(\theta_{x=0} - T_W) \tag{6a}$$

and

$$q_\omega = h'_3\,(T_W - \theta_{x=0}) \tag{6b}$$

while loss to the insulation from the absorbing surface is given by

$$Q_{ins.} = -K\left(\frac{\partial \theta}{\partial x}\right)_{I\,x=0} \quad \text{------}(7)$$

Where $\theta(x,t)$ is the temperature distribution in the insulation. Equations (1), (2) and (3) can now be rewritten as

$$M_g \frac{dT_g}{dt} = \tau_1 H_s + h_1 (T_w - T_g) - h_2 (T_g - T_a) \text{ --- }(8)$$

and

$$M_w \frac{dT_w}{dt} = \tau_2 H_s + h_3 (\theta_{x=0} - T_w) - h_1 (T_w - T_g) \text{ --- }(9)$$

$$\tau_3 H_s = h_3 (\theta_{x=0} - T_w) - K_1 \left(\frac{\partial \theta}{\partial x}\right)_{x=0} \text{ --- }(10)$$

Where h_1, h_2 and h_3 are defined in Appendix II.1.

The temperature distribution $\theta(x,t)$ in the insulation is governed by the one dimensional heat conduction equation and is given by

$$K \frac{\partial^2 \theta}{\partial x^2} = \rho c \frac{\partial \theta}{\partial t} \text{ --- }(11)$$

The energy balance of the surface of insulation in contact with air is given by, (the effect of box sheet thickness is neglected),

$$-K \frac{\partial \theta}{\partial x}\bigg|_{x=L} = h_4 (\theta_{x=L} - T_a) \text{ --- }(12)$$

The solar intensity and ambient air temperature can be considered to be periodic and hence can be Fourier analysed in the form;

$$H_S = a_0 + Re\sum a_n \exp(in\omega t) \quad --(13a)$$

and

$$T_a = b_0 + Re\sum_{n=1}^{\infty} b_n \exp(in\omega t) \quad ---(13b)$$

Where

$$\omega = 2\pi/24 \times 60 \times 60 \quad . \sec^{-1}$$

In view of Eqs.(13), we can assume the following periodic solutions;

$$\theta(x,t) = Ax + B + Re\sum_{n=1}^{\infty}\{C_n \exp(\beta_n x) + D_n \exp(-\beta_n x)\}.\exp(in\omega t).$$

and

$$T_g(t) = g_0 + Re\sum_{n=1}^{\infty} g_n \exp(in\omega t)$$

$$T_w(t) = H_0 + Re\sum_{n=1}^{\infty} H_n \exp(in\omega t)$$

where

A, B, g_0 H_0, C_n, D_n, g_n and H_n

are constants, to be determined from Eqs. (8),(10) and (14), and are given by

$$g_0 = b_0 + \frac{(T_1+T_2+T_3)}{h_2} - \frac{\frac{(T_1+T_2+T_3)}{h_2} + \frac{(T_2+T_3)}{h_1} + \frac{T_3}{h_3}}{h_2\left\{\frac{L}{K} + \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3} + \frac{1}{h'}\right\}}$$

$$H_0 = \frac{1}{h_1}\{(h_1+h_2)g_0 - h_2 b_0 - T_1 a_0\}$$

$$A_1 = \frac{h_2}{K}g_0 - \left(\frac{T_1+T_2+T_3}{K}\right)a_0 - \frac{h_2 b_0}{K}$$

$$= \left[\left\{ 1 + \frac{h_2(h_1+h_3)}{h_1 h_3} \right\} g_0 - \left\{ \frac{(T_1+T_2)h_1 + h_3 T_1}{h_1 h_3} \right\} - \frac{h_2(h_1+h_3)}{h_1 h_3} b_0 \right]$$

$$= \left[\frac{\frac{h' b_n}{k\beta_n} - \left\{ \left(1+\frac{h'}{k\beta_n}\right) M_6 \exp(\beta_n L) - \left(1-\frac{h'}{k\beta_n}\right) M_8 \exp(-\beta_n L) \right\}}{\left\{ \left(1+\frac{h'}{k\beta_n}\right) M_5 \exp(\beta_n L) - \left(1-\frac{h'}{k\beta_n}\right) M_7 \exp(-\beta_n L) \right\}} \right]$$

$= M_1 \; g_n + M_2$

$= M_5 \; g_n + M_6$

$= M_7 \; gn + M_8$

M's are,

$$= \left[in\omega M g + \left(\frac{h_1+h_2}{h_1} \right) \right]$$

$$= -\left[\frac{h_2 \, b_n}{h_1} + \frac{T_1 \, a_n}{h_1} \right]$$

$$= \left[\left(1 + \frac{h_1}{h_3} + in\omega M_W \right) M_1 - \frac{h_1}{h_3} \right]$$

$$= \left[\left(1 + h_1/h_3 + in\omega M_W \right) M_2 - \frac{T_2}{h_3} a_n \right]$$

$$= \frac{h_3}{2k\beta_n} \left[M_3 \left(1 + \frac{k\beta_n}{h_3}\right) - M_1 \right]$$

$$= \frac{h_3}{2k\beta_n} \left[M_4 \left(1 + \frac{k\beta_n}{h_3}\right) + \frac{T_3 a_n}{h_3} - M_2 \right]$$

$$= -h_3/2k\beta_n \left[M_3 \left(1 - \frac{k\beta_n}{h_3}\right) - M_1 \right]$$

$$= -h_3/2k\beta_n \left[M_4 \left(1 - \frac{k\beta_n}{h_3}\right) + \frac{T_3 a_n}{h_3} - M_2 \right]$$

Thus the heat flux per unit area, corresponding to evaporation is

$$Q_{ew} = h_w m_w = h_{eff} (T_w - T_g)$$
$$= h_{eff} \left[H_o - g_o + \sum_{n=1}^{\infty} (H_n - g_n) \exp(in\omega t) \right] \quad -(13)$$

where h_{eff} is evaporative heat transfer coefficient from water surface to the glass and is defined in Appendix. The mass of water M evaporating per day in Kg/m^2 day can be obtained by integrating the RHS of Eq.(13) over 24 hours (one full period); thus

$$M = \int_0^{24 \times 60 \times 60} h_{eff} \cdot \frac{(T_w - T_g)}{h_w} \cdot dt$$

$$= \frac{h_{eff} (H_o - g_o)}{h_w} \times 24 \times 60 \times 60 \quad Kg/m^2 day \quad -(14)$$

In the case of water with Dye, $h_3 = -h'_3$, (Eqn. 6b).

NUMERICAL CALCULATIONS AND DISCUSSION

Numerical calculations were made corresponding to our experimental solar still. The relevant parameter were:

Without Dye	With Dye
$\omega = 7.2722 \times 10^{-5}\ s^{-1}$	$\omega = 7.2722 \times 10^{-5}\ s^{-1}$
$\rho = 64.08\ Kg/m^3$	$\rho = 64.04$ Kg/m3
$C = 670\ J/Kg\ ^oC$	$C = 670\ J/Kg\ ^oC$
$K = .04\ W/m\ ^oC$	$K = .04\ W/m\ ^oC$
$L = .05$ m	$L = .05$ m
$Mg = 5226\ J/m^2\ ^oC$	$Mg = 5226\ J/m^2\ ^oC$

$M_w = 672634\ J/m^2\ {}^oC$	$M_w = 672634\ J/m^2\ {}^oC$
$\tau_1' = 0.1$	$\tau_1' = 0.1$
$\tau_2' = 0.0$	$\tau_2' = 0.8$
$\tau_3' = 0.6$	$\tau_3' = 0.06$
$h_1 = 22.52\ W/m^2\ {}^oC$	$h_1 = 24.42\ W/m^2\ {}^oC$
$h_2 = 50\ W/m^2\ {}^oC$	$h_2 = 50\ W/m^2\ {}^oC$
$h_3 = 135.05\ W/m^2\ {}^oC$	$h_3' = 67.53\ W/m^2\ {}^oC$
$\alpha = 6.2472\ m^{-1}$	$\alpha = 6.2472\ m^{-1}$
$h_{eff} = 14.01\ W/m^2\ {}^oC$	$h_{eff} = 15.51\ W/m^2\ {}^oC$
$h_4 = 6.2472\ W/m^2\ {}^oC$	$h_4 = 22.08\ W/m^2\ {}^oC$

In the temperature range of our experimental observations (15–65 ^oC), the following linear relation obtained from least square fitting of data is used for calculating the saturation vapour pressure :

$$p = 420.69\ T - 1.22239 \times 10^5$$

where p is expressed in N/m^2 and T in ^oK, the plot of this relation and data taken from the steam table (Schmidt, 1969) are shown in Fig.II-2, in the temperature range 293^o K – 337^oK.

The calculated hourly variations of distillate per unit basin area, with and without dye present, are shown in Fig.II.3. Fig. II.4 a and II·4b present the calculated hourly variation of glass and water temperatures, respectively; the experimental points are shown by circles. Fig. II.5 shows the variation in the ratio of distillate outputs, with and without dye (black, LHS scale), and the distilled water productivity in the two cases

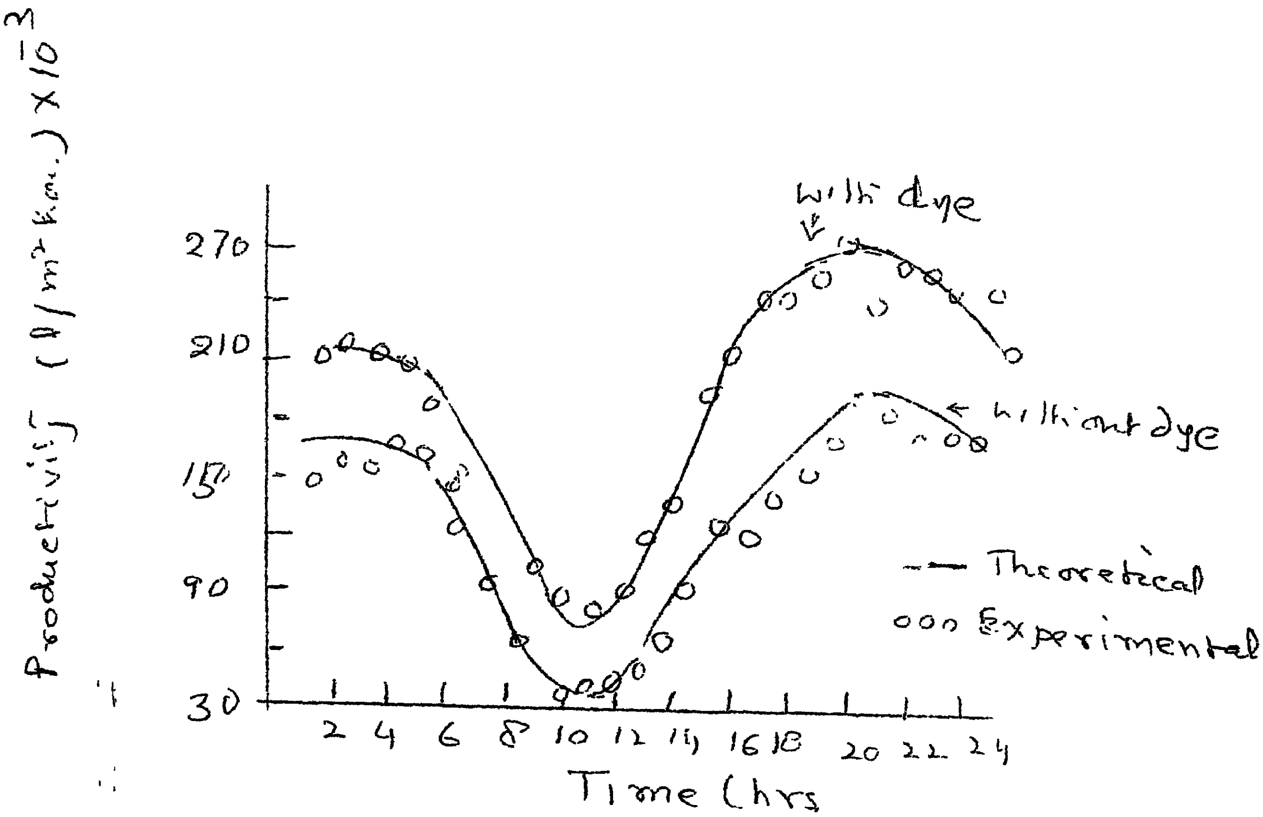


fig II.3 Hourly variation of distillate for Square meter.

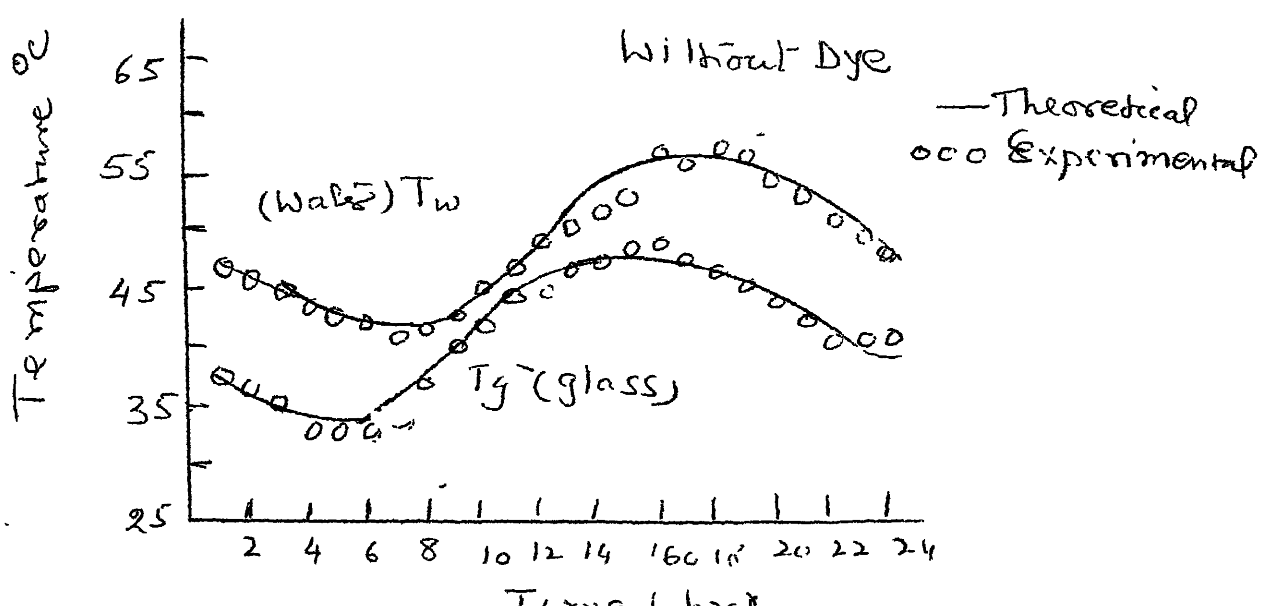


Fig II.4a Hour variation of Temperature without dye.

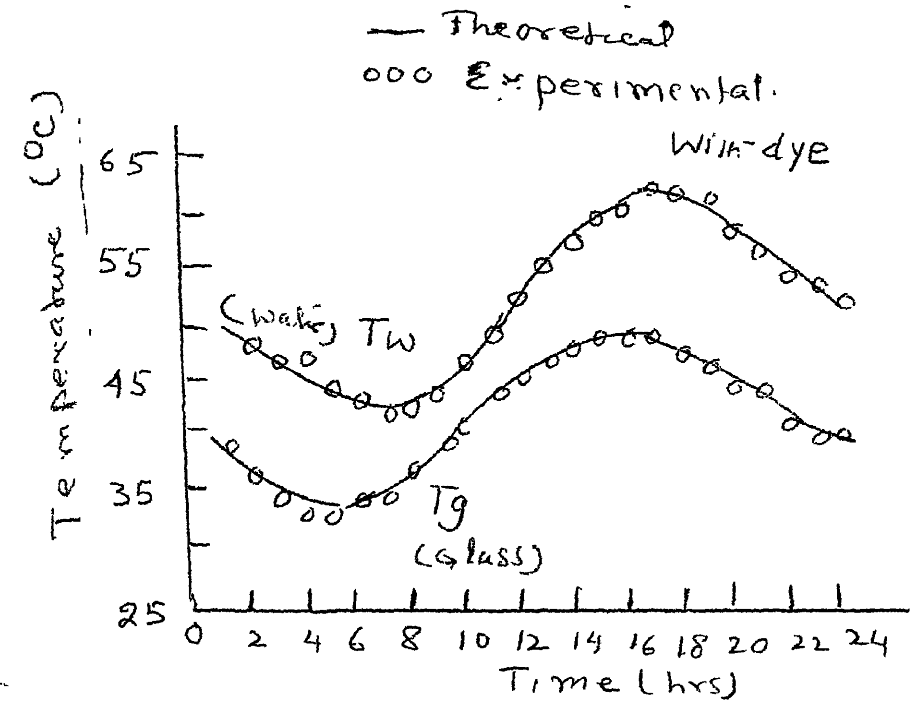


Fig II.4 b: Hourly variation of temp in still containing dye

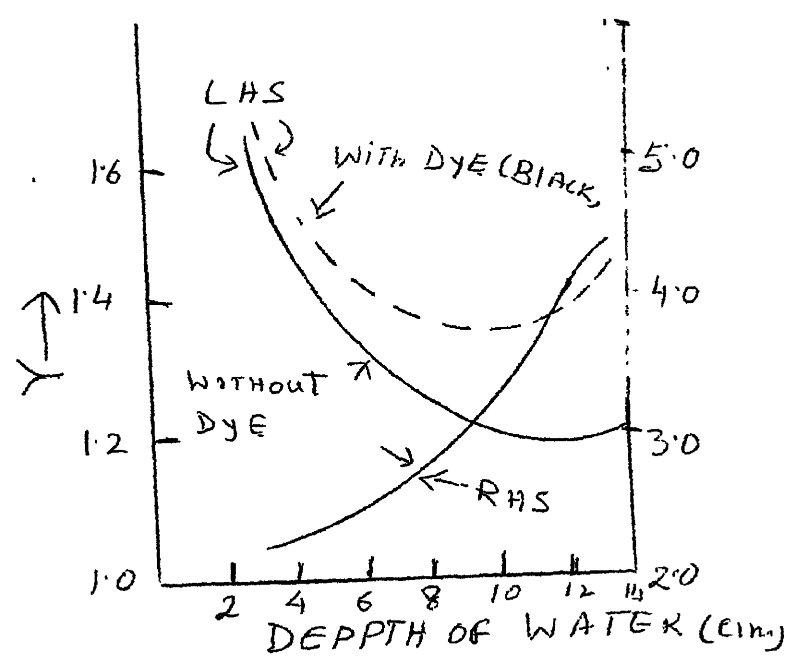


Fig: II.5 : Variation of ratios of out-put with and without dye (Black)

(RHS scale), with water depth. The calculated effects of insulation thickness and the absorptivity of the dye are shown in Figs. II.6 and II.7, respectively.

The hourly variations of the solar intensity on the glass surface are plotted in Fig. II.8. It is evident that the six harmonics used in our calculations are sufficient for the convergence of the Fourier series (see Tables II.1 and II.2).

Figures II.3 and II.4 show that the calculated results are in good agreement with the experimental observations.

CONCLUSIONS

(1) The theory is valid only for a large basin water mass because, in such cases, the evaporative losses are small compared with the actual water mass. This corresponds to the assymptotic part of Fig.II.5 (see also Fig.3 of Bloemer et. al. (1965) and Fig.8 of Cooper, 1969). If, however, smaller water depths are maintained, as is necessary for maximum productivity, the amount of distillate can not be estimated- by the present theory. However, from maintenance point of view, large water depths are prefereed (Bloemer et.al. 1965).

(2) The black dye injected in the water increased the productivity by $48^{0}/_{0}$ for 14cm. depth (Fig. II.5).

(3) The productivity increases rapidly with increasing insulation thickness up to 4cm. and then more slowly in both cases

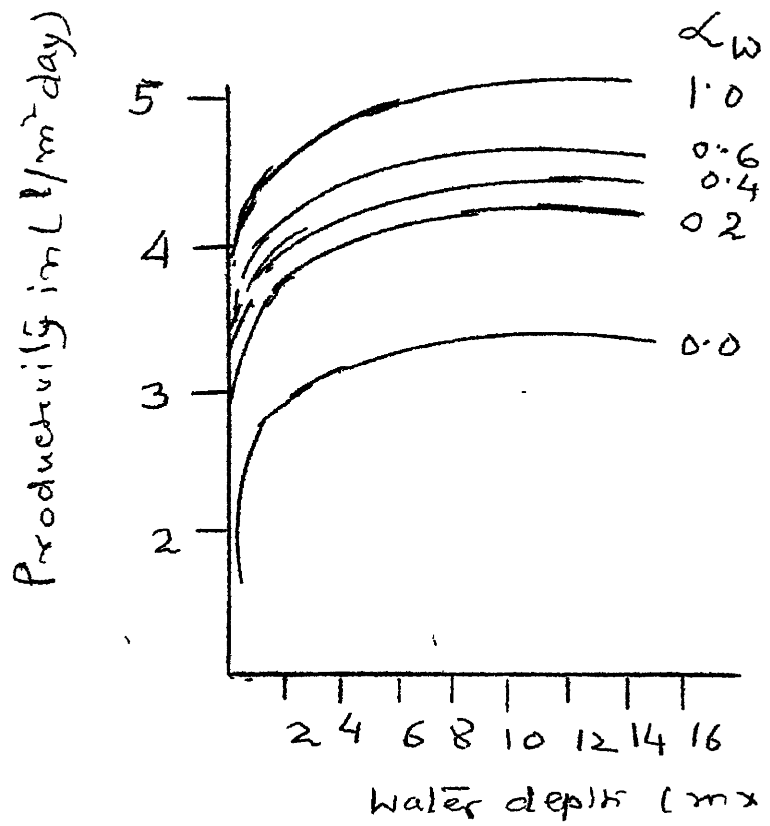


Fig II.6 Variation of daily distillate output of the still for different water absorptivities with water depth

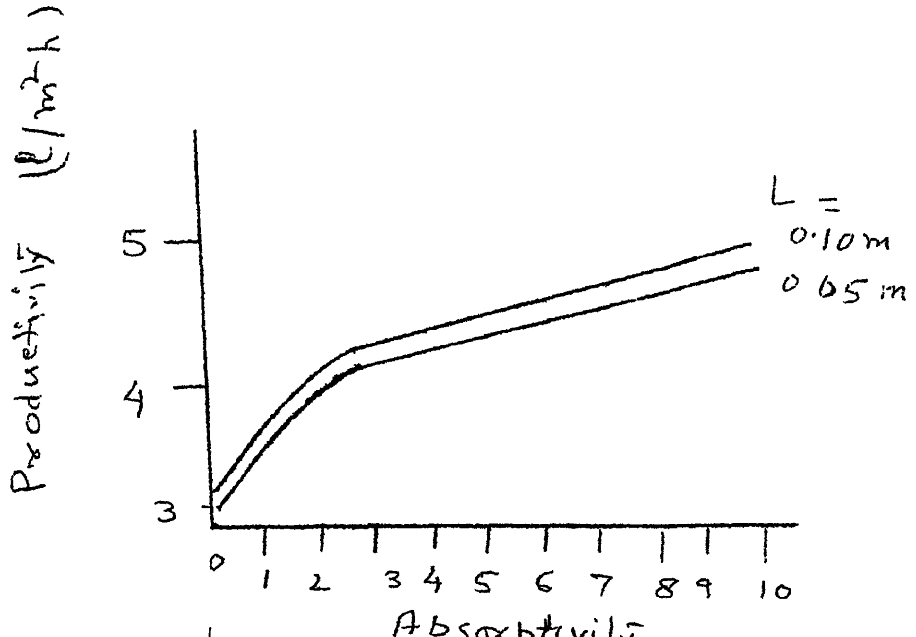


Fig II. 7 Variation of still productivity with Insulation..

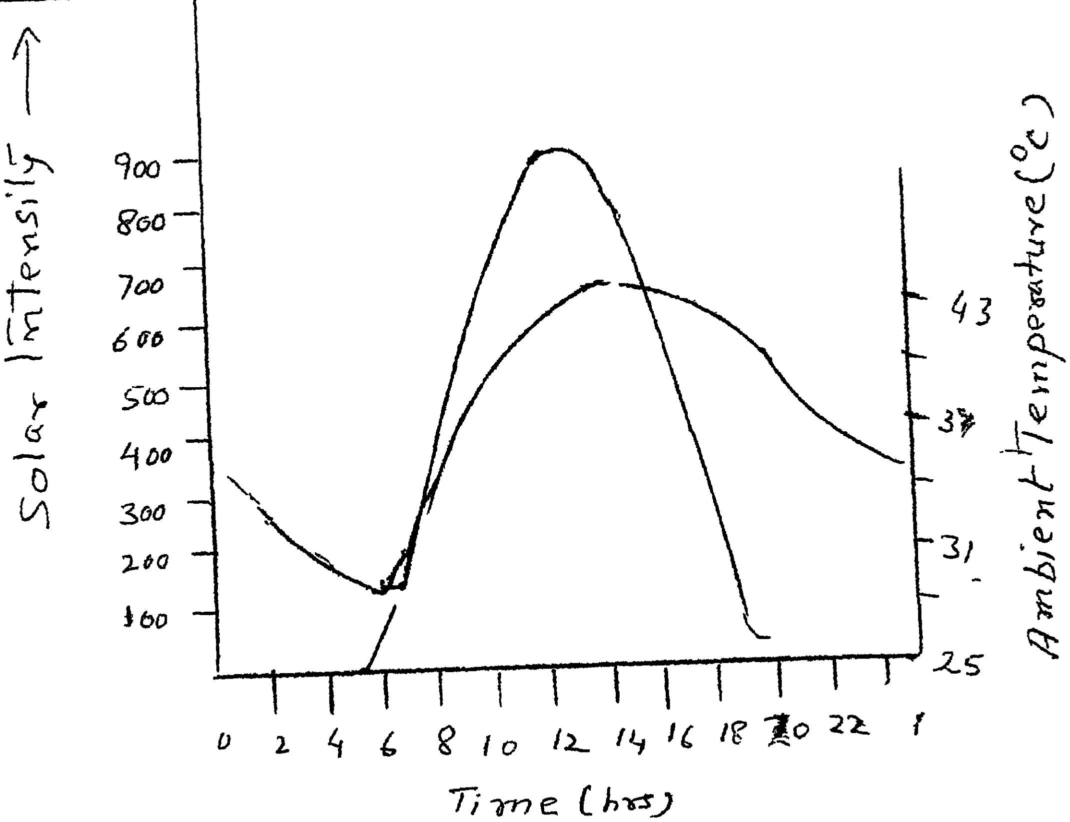


Fig II 8 Hourly Variation of Solar Intensity and air Temperature. For June 14, 79.

<u>Table-II.1</u>

Fourier coefficients of Solar Intensity available on the glass surface

n	0	1	2	3	4	5	6
An (W/m^2)	305.0554	457.165	157.995	18.917	22.051	18.089	7.6910
ϕ_n (Degrees)		188.961	20.850	4.459	235.161	183.168	48.247

<u>Table-II.2</u>

Fourier coefficients of Ambient Air Temperature

n	0	1	2	3	4	5	6
B_n	36.6958	6.666	1.065	0.045	0.300	0.298	0.157
ϕ_n (Degrees)		230.105	351.466	77.879	155.915	299.941	25.516

(with or without the dye being present, Fig.II.6).

(4) The productivity increased rapidly for low absorptivity systems and then tends to saturate with increasing absoptivity (Fig.II.7).

(5) Not more than one harmonic as been used in earlier analyses of the solar still (Hirshmann et. al. 1970, Baum et.al. 1970). It is impossible to reproduce solar intensity and ambient air temperatures with one harmonic only. Hence one needs to consider more harmonics. As has been mentioned earlier, six harmonics are found to be a good representation of the observed variation.

APPENDIX-II.1

Heat Transfer to Atmosphere

The combined radiative and conventive losses to the atmosphere can be written as,

$$Qa = h_{ca}\,(T_g - T_a) + \epsilon_g\,\sigma\left[(T_g + 273.15)^4 - (Ta + 261.15)^4\right], \quad \text{--(I-}$$

$$h_2 = h_{ca} + \frac{\epsilon_g\,\sigma\left[(T_g + 273.15)^4 - (T_a + 261.15)^4\right]}{(Tg - Ta)}, \quad \text{--- (I-}$$

$$h_{ca} = 5.7 + 3.8\ V,\ V \text{ in Kmph}$$

In evaluating h_2 from Eq. I-2, the mean values for temperatures T_g and T_a can be used.

Internal Heat and Mass Transfer

The radiation, convection and evaporation between the water surface and cover glass can be approximated as that between two infinite prallel planes. The following equations proposed by Dunkle. are used to describe these modes:

Radiative loss of water to glass is given by

$$Q_{rw} = 0.9\,\sigma\left[(T_w + 273.15)^4 - (T_g + 273.15)^4\right] \quad \text{--(I-3)}$$

$$h_{rw} = \frac{0.9\,\sigma\left[(T_w + 273.15)^4 - (T_g + 273.15)^4\right]}{(T_w - T_g)} \quad \text{---(I-4)}$$

which neglects successive specular reflection between the transparent cover and water surface.

Convective loss of water to glass is given by

$$Qcw = 0.884\left[(T_w - T_g) + \frac{R_1\,(Tw - T_g)\,(Tw + 273.15)}{(268.9x\ 10^3 - R_2 - R_1\ Tw)}\right]^{1/3} \times (T_w - T_g) \quad \text{---(I-}$$

$$h_{cw} = 0.884\left[(T_w-T_g) + \frac{R1(T_w-T_g)(T_w+273.15)}{(268.9\times10^3 - R_2 - R_1 T_w)}\right]^{1/3} \quad \text{---(I-6)}$$

While evaporative loss is given by

$$Qew = 16.276 \times 10^{-3}\ Qcw.\ R_1\ (Tw-Tg) \quad \text{---(I-7)}$$

$$heff = 16.276 \times 10^{-3}\ hcw.R_1 \quad \text{---(I-8)}$$

$$h_1 = heff + hcw + hrw \quad \text{---(I-9)}$$

Where hrw, hcw and heff are calculated from equations (I-4), (I-6) and (I-8), by taking the mean values for temperatures Tw and Tg.

NOMENCLATURE

C Specific heat of insulation, J/Kg

Cp Specific heat of water, J/Kg ^oC

hca Convective heat transfer coefficient from glass to the ambient, $W/m^2\ ^oC$.

hra Radiative heat transfer coefficient from glass to the ambient, $W/m^2\ ^oC$.

hcw Convective heat transfer coefficient from water surface to the glass, $W/m^2\ ^oC$.

hrw Radiative heat transfer coefficient from water surface to the glass, $W/m^2\ ^oC$.

heff Evaporative heat transfer coefficient from water surface to the glass, $W/m^2\ ^oC$.

h_3 Heat transfer coefficient from the absorbing surface to the water, $W/m^2\ {}^oC$.

h'_3 Heat transfer coefficient from the water mixed with dye to basin surface, $W/m^2\ {}^oC$

h_4 Heat transfer coefficient from insulation to the ambient $W/m^2\ {}^oC$.

hw Latent heat of vaporization of water, J/Kg.

K Thermal conductivity of insulation, W/m^oC

L Thickness of insulation, m

M_g Heat capacity of glass per unit area, $J/m^2\ {}^oC$

M_w Heat capacity of water per unit area $J/m^2\ {}^oC$

m concentration of water containing dye, gm/litre

p Partial pressure of water vapour at temperature T, pa

p_w Partial pressure of water vapour at water temp, pa

p_g Partial pressure of water vapour at glass temp, pa

Q_a Combined convective and radiative heat transfer from glass to the ambient, W/m^2

Qcw Convective heat transfer from water to the glass, W/m^2

Qew Evaporative heat transfer from water tothe glass, W/m^2

Qrw Radiative heat transfer from water to the glass, W/m^2

Qins. Energy loss to the insulation by the absorbing surface, W/m^2

Rg Reflectivity of the glass

Ta Temperature, ^oK

Tg Glass temperature, ^oK

Tw Water temperature, ^oK

t Time, S

X Position, coordinate vertically downward, m

Y Water depth, m

V Wind velocity, m/s

ϵ_g Emissivity of glass

ρ Density of insulation, Kg/m^3

σ Stefan-Boltzmann constant, 5.6697×10^{-11} KW/m $^oK^4$

Υ_1 Fraction of energy absorbed by glass

Υ_2 Fraction of energy absorbed by water

Υ_3 Fraction of the energy absorbed by the black surface of the basin

α_g Absorptivity of the glass

α_w Absorptivity of the water

β_n Characteristic length of the water. $(conm)^{-1}$

an An exp $(-i\sigma_n)$

bn βn exp $(-i\phi_n)$

An, Bn, σn and ϕn are given in Tables I and II respectively

CHAPTER-III

EFFECT OF DYES ON SOLAR WATER DISTILLATION

Summary

Effect of different dyes on the rate of distillation in a solar still has reported in this chapter. 14 Organic and 3 Inorganic dyes have been studied at different sets of water depths/dye concentrations. The extent of increase was found to be dye specific rather than colour. Seasonal variation on the still performance on two dyes for two years has shown that some of the dyes were quite stable.

Field trials on a large solar distillation plant (at Avania village in Bhavnagar) showed that the increase in distilled water produced is much more than that obtained in laboratory scale stills.

Interlaboratory comparison on laboratory scale stills have given comparable results.

The research on solar stills has mainly been directed towards improvement/change in design or materials used in fabrication of stills to obtain better efficiencies, however practically no systematic effort has been made towards liquid collector property of the brackish water itself. Garg & Mann(1976) reported their observations/data(Table III.I) on the distillate output of solar stills containing coloured brackish water but without any details as to the name or concentration of the colouring agent. Recently Rajvanshi (1981) has reported a somewhat detailed study on the effect of dyes on solar water distillation but have restricted the work on 3 colours. A brief account of their experimental data has been reproduced in Table III.2 which indicates the limited academic approach of the work and called for a detailed study. The present chapter deals with the results, obtained on the productivity of the (laboratory scale) solar stills in presence of different dyes both as functions of concentration as well as depth of (brackish) water. The details with regard to colour, name, concentration of the dyes and water depth studied during the course of this project have been given in Table III.3.

EXPERIMENTAL

ɔpic Studies:-

ɜntioned earlier that this work was based on the
ɲn of visible portion of the solar spectrum by
ɪixed brackish water rather than black bottom
ɪsin. It was therefore expected that the
ɔopic data on the aquous solutions of the dyes,
ɪdied, may provide the basis for selection of
dyes as well as their concentrations. Absorption
ɪf a number of dyes at different concentrations
ɪrded. A study of the spectra indicated that
spectra of the aquous solutions of most of the
ɪ at 50 ppm could not be recorded mainly due to
ɔpacity. The dye concentrations lower than 50 ppm
ːted later) were found to be of no use(as in case
concentrations the effect of black bottom of the
ɜ found to be predominant).

spectra of some of the dyes at much lower
ɪtions were also recorded, as shown in figure
ɪth a view to see the extent of absorption of dyes
ːtion of dye concentration, but the peak heights
ɪnds could not provide any useful information.
study though anticipated to provide considerable
could also have saved lot of time, had to be reject-

TABLE_III.1

EFFECT OF DYES ON THE DISTILLED WATER OUTPUT OF SINGLE SLOPED SOLAR STILL

Test No.	Distilled Water Output (l/m^2)		
	No colour in water	Blue colour in water	Red colour in water
1.	1.97	2.33	2.53
2.	1.79	2.14	2.33
3.	2.05	2.27	2.53
4.	2.29	2.52	2.75
Mean	2.02	2.31	2.53
Average increase in distillate output		14.36%	25.25%

* Data from Garg H.P. & Mann H.S., Solcar Energy 18, 159 (1976).

TABLE_III.2

Performance of different dyes reported in literature*

Sl. No.	Date of Experi-ment	Name/ colour of the dye	Solar[1] Radia-tions (Kj/day)	Concentra-tion of the dye (ppm)	Distillate (Kg.)		Efficiency[2]		Percent[3] Differenc
					Dye	Control	η_d	η_c	
A.	CARMOISINE								
1.	Nov. 26, 77	Red	21830	50	3.60	3.35	38.3	35.7	7.4
2.	Jan. 10, 78	Red	20410	100	3.05	2.55	34.8	27.4	19.9
B.	NAPTHYL-AMMINE 10 BR								
3.	March 17, 78	Black	33238	50	4.31	3.71	30.1	26.0	15.9
4	March 31, 78	Black	33086	172.5	5.31	4.53	37.3	31.8	17.1
5.	April 14, 78	Black	35864	172.5	5.60	4.35	36.2	28.1	28.8
6.	April 15, 78	Black	35085	172.5	5.54	4.37	36.8	28.9	26.9
C.	DARK GREEN[4]								
7.	May 15, 78	Green	40654	50	5.55	4.84	31.8	27.7	14.8
8.	Aug. 22, 78	Green	32598	100	5.19	4.64	37.0	33.1	12.0

Notes:

* Data from Rajvanshi A.K. Solar Energy 27, 51 (1981)

1. Solar Radiation (KJ/day) : KJ/m^2 day x 1.486 m^2

2. Efficiency η : $\dfrac{\text{Distillate output (Kg)} \times 2321\ \text{(KJ/Kg)}}{\text{Total Solar input (KJ)}}$

   η_c : Efficiency of the still without dye (control)

   η_d : Efficiency of the still with dye

3. Percent Difference = $\left\{\dfrac{\text{Distillate (dye} - \text{Distillate (control))}}{\text{Distillate (control)}}\right\} \times 100$

4. Dark green colour was prepared by mixing equal amounts (33% by weight) of each of Neptune BR (blue), Carmoisine (red) and Tetrazine 'C' extra (yellow).

TABLE_III.3

DYES AND THEIR CONCENTRATION/WATER_DEPTH STUDIED

Sl. No.	Colour	Name and quality of the dye	Concentration/water-depth		
A.	Organic Dyes:				
1.	Red	Congo Red	50/6	100/6	200/6
2.	Red	Congo Red	50/12	100/12	
			50/6	100/6	50/12
3.	Brown	Bismark Brown (AR)	50/6	100/6	200/6
			50/12	100/12	
4.	Violet	Ranocid Violet (AR)	50/6*	100/6	50/12
			(50+50/12≠	100/12	200/12
5.	Violet	Methyl violet (AR)	50/6	100/6	
			50/12*	100/12*	
6.	Violet	Crystal violet (AR)	50/6	100/6	
			50/12*	100/12*	
7.	Green	Napthol Green(Comm)	50/6*	100/6*	
			50/12	100/12	
8.	Green	Malachite Green (Comm)	50/6	100/6	500/6
			50/12*	100/12	
9.	Green	Ranocid Green(Comm)	50/6*	100/6	
			50/12*	100/12	
10.	Green	Direct Green (Comm)	50/6	100/6	
			50/12*	100/12	200/12
11.	Green	**PLX_Green (AR)	50/6	100/6	
			50/12*	100/12	
12.	Black	**Diphenyl Black(Comm)	50/6	100/6	500/6
				100/4	500/4
			50/12	100/12	1000/12
13.	Blue	**Methylene Blue (AR)	50/6	100/6	500/6
				1000/12	1000/6
				100/12	200/12
14.	Blue	**Methylene Blue(Comm)	50/6	100/6	100/12
15.	Blue-Black	Erlochrome Blue Black 'B' (AR)	50/6*	100/6	
			50/12	100/12	
16.	Blue-Black	Erlochrome Blue Black 'R' (AR)	50/6*	100/6	

... Contd...

Sl. No.	Colour	Name and quality of the dye	Concentration/water-depth	
B.	Inorganic Dyes:			
17.	Majanta	Potassium Permangnate (AR Grade)	50/6 200/6	100/6 100/12
18.	Light Blue	Cooper Sulphate (AR Grade)	50/6	100/6
19.	Yellow	Potassium chromate (AR Grade)	50/6	100/6

** Seasonal study on these dyes has also been done.

* Data for these sets were irregular and have not been given in the figure.

≠ Data for 50+50/12 were same as that of the set 50/12 (first set) and have not been included in the figure.

Comm: Commercial grade dye

AR: Analytical reagent mostly from Sigma.

b) Studies on Solar Stills:-

Having failed to get any purposeful information from the above study, it was decided to carry out experiments in actual systems (solar stills). In order to save both time and the dye, reasonably smaller stills,(.5mx .5m) made of aluminium, were fabricated, to obtain preliminary data with regard to the performance of the dye as well its concentration. These data were then used to decide about the suitability of a dye and also its concentration. The preliminary experiments were mainly done at 6 cm water depth.

The bigger solar stills, made of G.I sheets (.8mx.9m), were used for detailed studies. The details of the materials used for fabrication of these stills have been given in Table-III.4. Because of the large water mass, solar stills took 3-4 days to attain steady state.

Measurement of parameters like distillate output, ambient temperature, solar intensity and temperatures of brackish water as well as that of bottom surface and glass cover were made on daily basis. A few set of data in almost each experiment in morning and evening were also recorded. The optimum values for the thickness of the insulation (glass wool) and water depth were determined and found to be 4cm and 12cm for the big still and 3cm and 6cm for the small still containing dye mixed brackish water respectively.

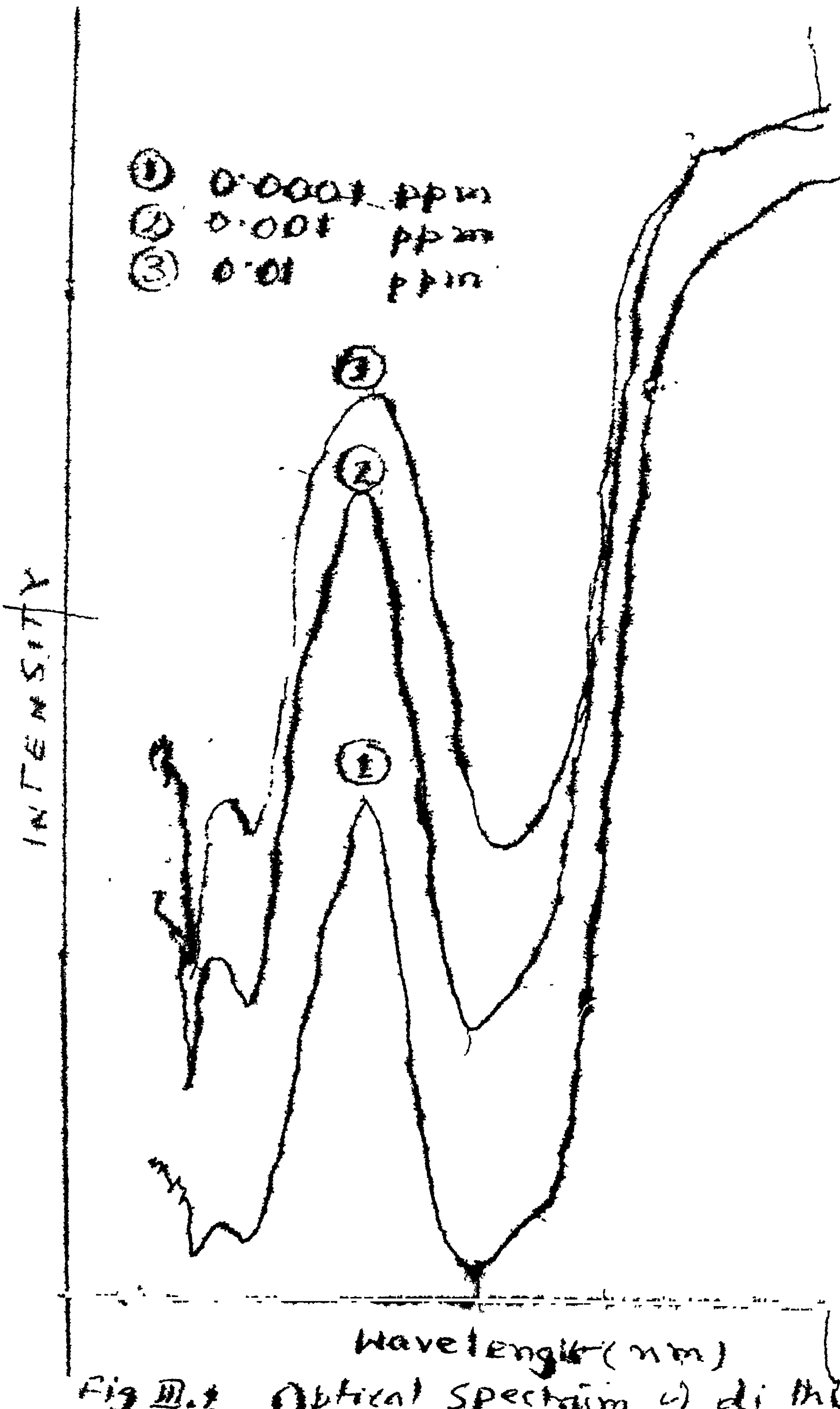


Fig III.1 Optical Spectrum of dithiazone at different Concentration

TABLE-III.4

DESIGN PARAMETERS OF SOLAR STILLS

Parameter (Basin Material)	Small Still (Aluminum Sheet)	Big Still (G.I. Sheet)
Basin Area	0.5 x 0.5m	0.8m x 0.9m
Effective Area	$0.239m^2$	$0.672m^2$
Glass Thickness	4 mm	4 mm
Glass Cover Angle	12°	10°
Insulation Thickness	3 mm	4 cm

The effect of dye has been reported in terms of percent increase in productivity (P) defined as,

$$P=\frac{\text{Still productivity with dye}}{\text{Still productivity without dye}}-1\Big)\times 100$$

The still productivity without dye was calculated using following relationship

Still productivity without dye=Productivity of the reference still X Correlation factor

Where correlation factor is the ratio of productivity of the experimental still (without dye) to that of the reference still (having identical size) under similar environmental conditions e.g. water depth, solar intensity, wind speed, still orientation etc. It may be mentioned that in order to ensure identical performance, stills having this ratio (correlation factor) between 0,9 and 1.0 were only used for experiments.

A number of stills were used for experimental work. One of these stills, whose performance was consistent was taken as the reference still. The correlation factors (with regard to distillate output) of other stills used be determined after each experiment. Data were taken only after the achievement of steady state i.e. when the consistency in the distillate output was observed. Correlation factor was determined on the basis of 5-6 days distillate output data. It may be mentioned that the correlation factors have not been reported separately, instead

have been included in calculation of "distillate output without dye". The daily data for individual dyes have not been given in the text (as most of these and other relevant informations have already been communicated to Tata Energy Research Institute Bombay, as a part of quarterly progress reports) except those having relevance to the discussions wherever required. However a coincise Table (III.5) giving average values of the distillate output and the percent increase in productivity for different dyes has been included.

Quality of the dye:-

Quality of the dye (whether commercial or A.R. grade) varied from dye to dye depending upon the availability as well as requirement. In case of some of the dyes, studies on both commercial and A.R. grade dyes were carried out to see the relative performance. All the experiments on a particular dye were done from the same lot, except in case of Methylene Blue. The quality of the dye has also been reported in Table III.3.

Results & Discussions

A number of studies on thermal energy balance and performance of the solar still have been reported. Some of these have also been supported by experimental data. For instance Bloemer et. al. (1965) reported the analysis with reference to heat distribution and main components of the energy losses in a still, for a typical set of parameters as given in Table III.6. A similar

TABLE III.5

Average Distillate Output in Presence of Organic - Dyes

Sl. No.	Name of the Dye	Concentration/water depth (ppm/cm)	Distillate Output ($1/m^2$ day)		Ratio	Percent increase	Month/Year of Observation.
			With Dye	Without Dye			
A.	Black	Diphenyl - Black (Commercial grade)					
1.		100/6	1.20	1.07	1.122	12.2	Oct. 80
2.		500/6 (Set I)	1.16	1.01	1.149	14.9	Jan. 80
3.		500/6 (Set II)	1.18	1.14	1.035	3.5	Feb. 80
4.		100/12	1.60	1.41	1.135	13.5	Feb. 80
5.		100/12	2.28	1.96	1.163	16.3	Mar. 80
6.		1000/4	4.75	4.45	1.067	6.7	Jun. 79
7.		1000/6	4.05	3.75	1.080	8.0	Jun. 79
8.		1000/8	3.75	3.30	1.136	13.6	Jun. 79
9.		1000/10	3.80	3.00	1.267	26.7	Jun 79
10.		1000/12	4.20	2.90	1.448	44.8	Jun. 79
11.		1000/14	4.30	2.90	1.483	48.3	Jun. 79
B.	Blue	Methylene Blue					
	(i) A.R. Grade						
12.		50/6	1.05	0.88	1.193	19.3	Oct. 81
13.		100/4	1.04	0.88	1.182	18.2	May 79
14.		100/6	1.01	0.90	1.122	12.2	Jul. 79
15.		500/6	1.04	0.97	1.072	7.2	---
16.		1000/6	1.19	0.90	1.322	32.2	Aug. 79
17.		100/12	3.19	2.45	1.302	30.2	Dec. 79
18.		200/12	3.05	2.81	1.085	8.5	Jan. 81
19.		1000/12	6.72	4.87	1.380	38.0	---

Sl. No.	Name of the Dye	Concentration/water depth (ppm/ cm)	Distillate Output ($1/m^2$ dya) With Dye	Without Dye	Ratio	Percent increase	Month/year of observation.
	(ii) Commercial grade						
20.		50/6	1.06	0.77	1.377	37.7	Oct. 81
21.		50/6	1.15	0.86	1.377	33.7	Mar. 82
22.		50/6	1.63	1.22	1.336	33.6	Mar. 82
23.		100/6	0.74	0.54	1.370	37.0	Nov. 81
24.		50/12	2.09	1.77	1.181	18.1	Mar. 82
25.		100/12	4.84	3.68	1.315	31.5	Oct. 81
C.	**Blue - Black - Eriochrome Blue Black**						
	(i) Blue Black 'B' (AR grade)						
26.		100/6	0.71	0.64	1.109	10.9	Dec. 79
27.		100/6	1.58	1.36	1.162	16.2	Feb. 80
28.		50/12	2.32	2.22	1.045	4.5	Mar. 80
29.		50+50/12	2.80	2.67	1.049	4.9	Apr. 80
30.		100/12	2.31	1.90	1.216	21.6	Sep/Oct. 80
	(ii) Blue Black 'R' (AR grade)						
31.		100/6	1.13	1.06	1.066	6.6	May 80
32.		100/12	2.42	2.16	1.120	12.0	Mar 80
33.		200/12	3.15	3.06	1.029	2.9	May 80
D.	**Violet**						
	(i) Crystal Violet (AR grade)						
34.		50/6	0.85	0.79	1.076	7.6	Sep 79
35.		100/6 (Set I)	0.97	0.84	1.155	15.5	Sep 79
36.		100/6 (Set II)	0.96	0.91	1.055	5.5	Sep 79
37.		1000/10	3.80	3.09	1.230	23.0	Jun 79

...3/...

Sl. No.	Name of the Dye	Concentration/water depth (ppm/cm)	Distillate Output ($1/m^2$ dye) With Dye	Without Dye	Ratio	Percent increase	Month/year of observation.
	(ii) Ranocid Violet (Commercial)						
38.		100/6	1.72	1.72	1.000	--	Mar 80
39.		50/12	2.18	2.11	1.033	3.7	Mar 80
40.		50+50/12	2.81	2.71	1.037	3.7	Apr 80
41.		100/12	3.05	2.81	1.085	8.5	May 80
42.		200/12	3.02	2.88	1.049	4.9	Apr 80
	(iii) Methyl Violet (Commercial)						
43.		50/6	2.28	1.99	1.146	14.6	Apr 80
44.		100/6	1.75	1.57	1.115	11.5	Apr 80
45.		100/6	1.60	1.41	1.134	13.4	Irregular data.
E.	Green						
	(i) Malachite Green (AR grade)						
46.		50/6	1.12	1.14	--	--	Jan 80
47.		100/6 (set I)	1.14	0.98	1.163	16.3	Jan 80
48.		100/6 (set II)	1.58	1.46	1.082	8.2	Feb 80 (Aging)
49.		500/6	1.04	0.92	1.130	13.0	Feb 80
50.		100/12	3.05	2.96	1.030	3.0	Apr 80
	(iii) Ramocid Green (Commercial grade)						
51.		100/6	2.37	2.10	1.129	12.9	May/Jun 80
52.		100/12	3.01	2.85	1.056	5.6	Jun 80
	(iii) Napthol Green (Commercial grade)						
53.		100/6	1.60	1.60	1.000	--	Apr 80
54.		100/12	2.65	2.45	1.082	8.2	Jun 80

V...

Name of the Dye	Concentration/water depth (ppm/cm)	Distillate Output ($1/m^2$ day) With Dye	Without Dye	Ratio	Percent increase	Month/year of observation.
(iv) Direct Green 'B' (Commercial grade)						
	50/6	0.78	0.69	1.130	13.0	Dec 81
	100/6	1.65	1.49	1.107	10.7	Mar 81
	100/12	3.21	2.66	1.207	20.7	Apr 81
	200/12	3.19	3.05	1.046	4.6	May 81
(v) PLX - Green (AR Grade, BASF Germany)						
	50/6	1.36	1.20	1.133	13.3	May 81
	50/6	0.61	0.52	1.173	17.3	Jun 81
	100/6	1.29	1.10	1.173	17.3	May 81
	100/6	1.52	1.24	1.226	22.6	May 81
	100/6	1.03	0.85	1.212	21.2	Jun 81
	100/12	2.90	2.47	1.174	17.4	May 81
Red - Congo Red						
(i) Commercial Grade						
	50/6	0.95	0.71	1.338	33.8	Feb 82
	100/6 (set. I)	0.73	0.56	1.304	30.4	Jan 82
	100/6 (set. II)	0.67	0.54	1.241	24.1	Jan 82
	50/12	2.51	2.27	1.106	10.6	Dec 81 (from different lot)
	1000/10	3.30	3.07	1.075	7.5	Jun 79 (from different lot)

Table III.5 Contd...

...5/...

Sl. No.	Name of the Dye	Concentration/water depth (ppm/cm)	Distillate Output ($1/m^2$ day) With Dye	Without Dye	Ratio	Percent increase	Month/year of observation.
	(ii) AR Grade						
70.		50/6	1.36	1.45	- -	--	Sep 80
71.		50/6	1.51	1.18	1.280	28.0	Sep 80
72.		50/6	1.01	0.76	1.329	32.9	Sep 80
73.		100/6	1.91	1.69	1.130	13.0	Jun 81
74.		200/6	1.98	1.65	1.200	20.0	Jun 81
75.		50/12	2.73	2.47	1.105	10.5	Dec 81
G.	Brown Bismark Brown (AR grade)						
76.		50/6	2.57	2.27	1.132	13.2	May 80
77.		100/6	2.28	2.12	1.076	7.6	Apr 80
78.		200/6	2.19	2.03	1.079	7.9	May 80
79.		50/12	5.62	4.81	1.168	16.8	Sep 80
80.		100/12	2.62	2.40	1.092	9.2	Dec 80

study reported by Gomkale and Datta(1976) also showed that only about 38% of the incident energy is used effectively for evaporation while as much as one-third of this is wasted as thermal losses (Table.III.7)

Cooper has carried out a detailed study on solar stills mainly theoretical-but some of them are also supported by experimental data. For a single effect still with a shallow water depth and without conduction losses through the bottom and sides, Cooper (1969) suggested a maximum efficiency of 60% which went down to 40-46%, (Cooper 1972), when periodicity of insolation and ambient temperature as well as small conduction were included from experimental studies Cooper (1973) suggested 50% to be the maximum possible efficiency. Cooper (1972) has also reported the distribution of incident solar energy in a conventional still as per following details.

(i) nearly 2-6% is reflected back by clear (brackish) water.

(ii) about 30% is absorbed by the water and

(III) rest is transmitted (through the water), which is further reflected and absorbed by the black bottom of the still.

It may be noticed that the extent utilization of incident solar radiations can be incresed by reducing reflection losses (e.g. process (i) and (iii)) and increasing the absorption by the water to be distilled. Colouring of brackish water by a suitable water soluble dye is one of the ways as possibility of both the reflection and transmission

TABLE_III.6

DISTRIBUTION OF THERMAL ENERGY IN A SOLAR STILL*

Sl. No.	Parameters	Fraction of the total
1.	Effective evaporations of distillate	31.0%
2.	Ground and edge heat losses	2.0%
3.	Solar Radiations reflected from still	11.0%
4.	Solar radiations absorbed by the glass cover	5.0%
5.	Radiation losses from basin water to the glass cover (single largest loss)	26.0%
6.	Internal convection	8.0%
7.	Re-evaporation of distillate and unaccounted for losses	17.0%
		100.0%

*Data from Bloemer J.W., Irwin J.R., Eibling J.A. and Lof G.O.G., Solar Energy, 9 197 (1965)

TABLE III.7

CUMMULATIVE HEAT BALANCE OF SOLAR STILL*

Sl. No.	Details	K.Cal./ m^2. day	Percent
1.	Net solar radiation input	6386	100.0
2.	Heat energy to evaporation	2626	38.4
3.	Heat loss by convection from water to glass cover	253	3.7
4.	Heat loss by radiation from water to glass cover	837	12.2
5.	Heat loss by reflection from water to glass cover	684	10.0
6.	Heat absorbed by glass cover	684	10.0
7.	Heat loss from solar still bottom	1094	16.0
8.	Unaccounted losses due to vapour leakage and side losses	658	9.0

* Data from Gomkale S.D. & Datta R.L., Annals of Arid Zone 15(3), 206 (1976).

(due to optical opacity of solution) will be reduced and a considerable fraction of both these will be absorbed by the water leading to greater utilization of the incident solar energy. This is further supported from the fact that solar spectrum falling on Earth (≅0.3 μm to 3.2μm) occupies a small part of the specifically identified wavetypes through the energy content as well as the fraction of visible and infra red portions (of the solar spectrum are nearly equal, (Table III.8) however the distillation process in the solar still is mainly based on the utilization of infra red and with a marginal contribution from visible portion of the incident solar spectrum. This, thus further supports of the fact, that use of dye can improve the efficiency of the still. Experimental work, therefore, was initiated with a view to identify suitable dyes and the optimum conditions (e.g. water depth, dye concentration etc.) for the best performance of the dye (i.e. still productivity).

During the course of work, it was found that the presence of dye at lower water depth or low dye concentration did not show any significant increase in distillate output. This behaviour seems to be due to the fact that the extent of absorption at lower water depth or water containing smaller quantities of dye was same as if it were a conventional still with black bottom. The experiments, therefore were done to study effect of water depth and concentration on the performance of still in presence of dyes.

The figure II.6 gives the performance of still as a function of water depth for one of the dyes (black dye; 1000 ppm). It may be noticed from the figure, that the distillate output increased with the increase in water depth upto 12 cm after which increase was very little, 12 cm depth therefore was taken to be the optimum water depth for big stills. A similar-study on small stills gave 6 cm to be the optimum value. These water depths have, therefore, been used for most of the work presented.

Effect of concentration of dye on the performance of stills at constant water depth has also been studied for one of the dyes (blue dye) and shown in figure III.2. It may be noticed that an increase in dye concentration, as expected, produced higher distilled water but there is not correlation between the dye concentration and distilled water produced. The most plausible explanation for this could be the observed fact that the shinning layer (film of dye) on the water surface formed at higher dye concentrations reduces the distillate output in two ways (i) a major portion of the incident radiations are reflected (instead of being absorbed) and (ii) being a surface evaporation phenomenon, this film on water surface restricts free evaporation.

The performance of stills in presence of different organic dyes has been reported in figure III.3 as percent increase in distilled output (P) for different set of dye concentration and

TABLE_III.8

ENERGY CONTENT OF SOLAR SPECTRUM

Sl. No.	Factors	Solar Spectrum		
		U.V.	Visible	Infra Red
1.	Wave length range (μm)	Below 0.38	0.38-0.78	Above 0.78
2.	Average energy	95 W/m^2	640 W/m^2	618 W/m^2
3.	Fraction of total energy	0.70	0.4729	0.4571
4.	Average transmitivity of diffused radiations	- -	0.65	- -
5.	Fraction of total energy of the incident solar radiations	- -	0.30745	- -
6.	Reflectivity by the glass cover of solar still	- -	0.04	- -
7.	Absorptivity of the glass cover	- -	0.02	- -
8.	Fraction of total energy passing through the glass cover	--	0.23926	--

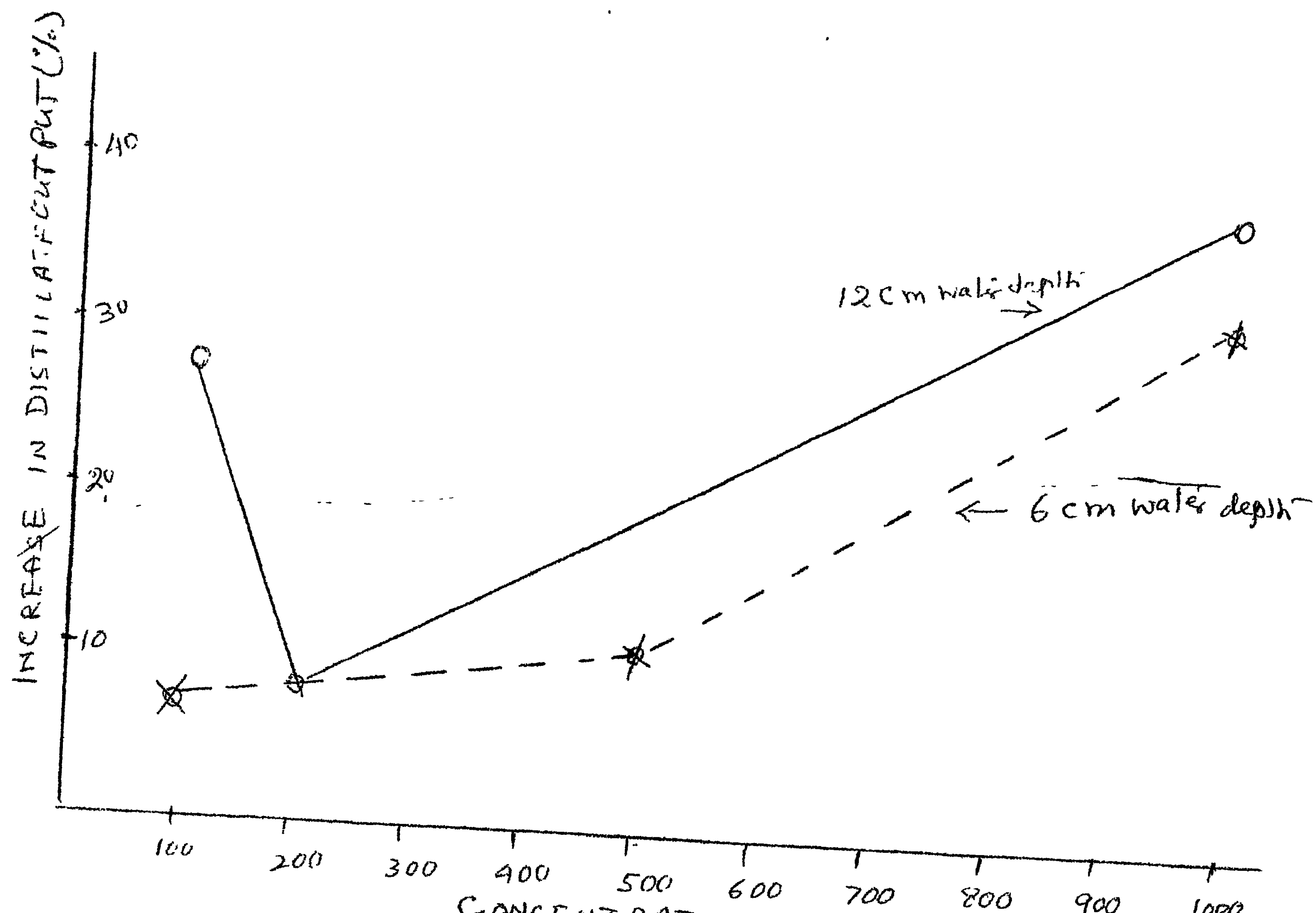


Fig. III-2 EFFECT OF DYE CONCENTRATION AT CONSTANT WATER DEPTH

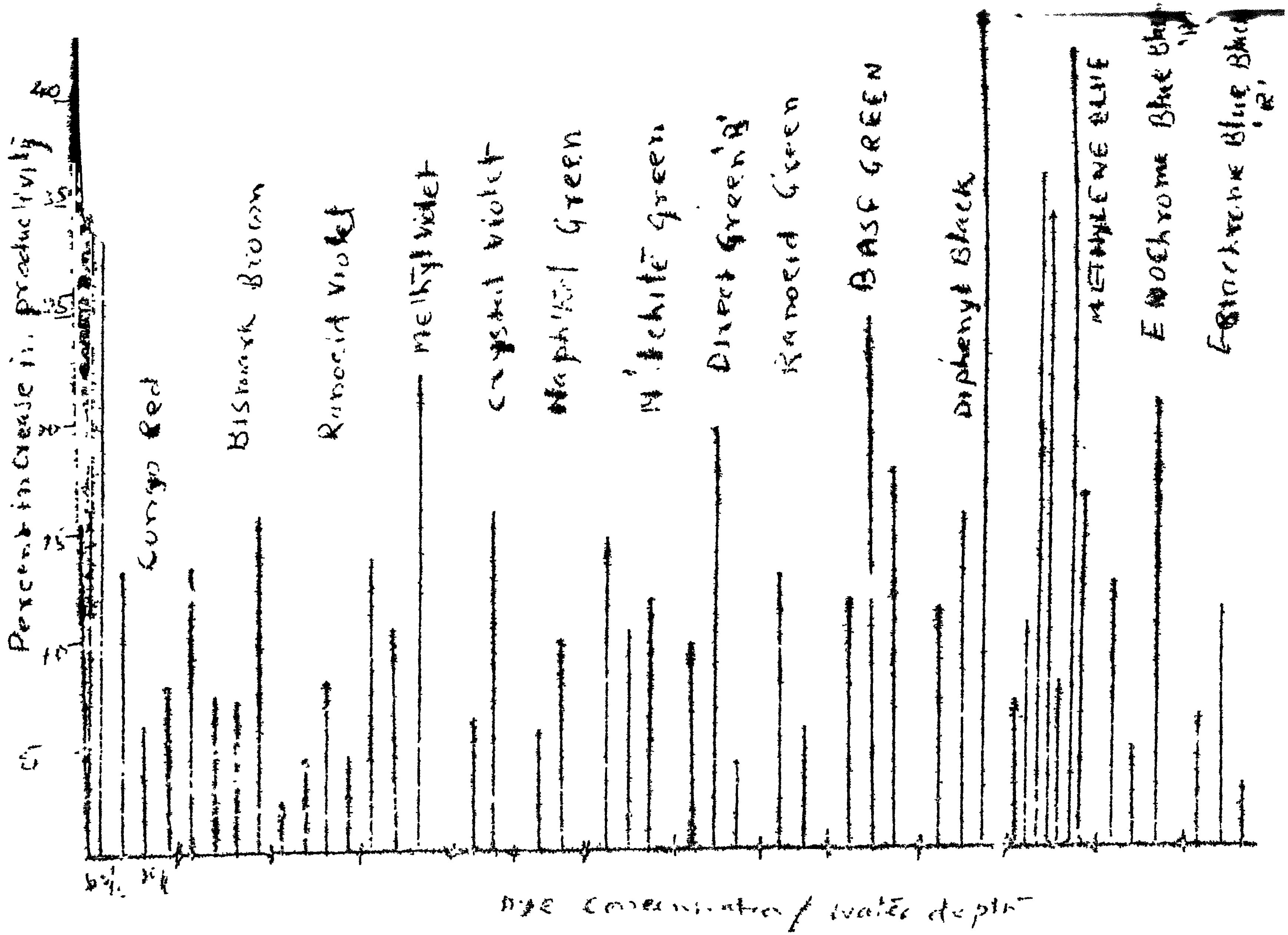


Fig III.3 Performance of organic dyes

water depths. It may be pointed out that while Table.III.3 gives details of the sets on which experments were done but the sets for which consistent data were obtained have been reported in figure III.3. An observation of this figure indicates that for most of the dyes the expected trend is followed viz. increase in concentration at constant water depth or increase in water depth at same concentration, both increased the distillate output with the exception of higher concentrations (due to formation of shinning layer).

Another observation is that the effect of dyes has been found to be dye specific rather than colour depedent. This behaviour is in accordance with the fact that optical absorption is a characterstic property of the dye.

Brief account of the performance of individual organic dyes

(i) Black: Dephenyl Black (Commercial grade)

Theorectically black colour is expected to be the most effective for its maximum absorption in the visible region. This is also evident from the fact that black coated surfaces have commonly been used as collectors in solar appliances. In view of this, the first dye studied was a black dye and detailed study both experimental and theoretical analysis was undertaken and has been presented in the proceeding Chapter(II). Among the various parameters studied in presence of this

dye included effects of thickness of insulation, water depth, dye concentration etc.

One of the observation was that though the higher dye concentrations 1000 ppm at 14 cm water depth increased the distillate output by 48% but there was no correspondence between concentration and the extent of increase in distillate out put, e.g. at 100 ppm and 12 cm water depth was found to be ~ 15%. The data on this dye showed that the performance of this dye was relatively better at 6 cm water depth rather than 12 cm. However, this was one of the most stable dyes in sun light and gave consistent performance for longer periods. The seasonal study on this dye was also carried out.

2. Blue: Methylene Blue - A.R. Grade (i) Sigma; (ii) Lobochem. } A.R.Grade (iii) Commercial grade

The data on this dye for different sets of dye concentrations/water depths showed that the relative behaviour of this dye was similar to that of black dye except that the extent of increase in output at lower concentrations (50 and 100 ppm) was higher than that of black dye. Relatively better performance of this dye could be due to (a) higher liquid collector (solar) efficiency and/or (b) efficient release of stored thermal energy by dye mixed (brackish) water. Since absorption in the visible portion of the

solar spectrum by blue dye is expected to be less than that by black dye, latter seems to play a predominant role and should be responsible for higher distillate output. It may be mentioned that the increase was better at lower water depth.

Blue-Black: (i) Eriochrome Blue Black 'B' } AR Grade Sigma
(ii) Eriochrome Blue Black 'R'

Having obtained encouragin data on the blue and black dyes, it was expected that a combination of these two colours may prove to be more effective than either. Data on the performance data above mentioned two dyes were collected. It can be seen that the extent of increase in still productivity in presence of these dyes was different, performance of Blue Black 'B' being better than that of Blue Black 'R' (For 400 ppm/12 cm. set increase in distillate output being 21.4% and 11.7% respectively). This thus shows that the use of combination of the two colours may give better results inview of the fact that the two factors mentioned in case of blue dye may, effectively, contribute in the distillation process.

Violet: Crystal Violet - A.R. Grade (Sigma)
Ranocid Violet - Commercial Grade
Methyl Violet - Commercial Grade

Initial work on crystal violet was done in June 1979 at 1000 ppm and 10 cm water depth which increased the distillate output by 23%. However the colour faded out in 4-5 days leading to reduction in the distillate output. Appearance of a brown coloured material at the bottom indicated the possibility of (photo) decomposition of the dye in sun light. In view of the relatively good performance of this dye, studies on two more dyes namely Ranocid Violet and Methyl violet were undertaken with a view to see the performance as well as stability of dye in sun light. It may be seen from the data, that while behaviour of Ranoncid violet was similar to that of crystal violet however, best performance of methyl violet was found for the set 50 ppm/6cm (increase being 15%). It may be concluded that violet dyes can not be used because of both the low extent of increase in output as well as their instability in sun light.

5. <u>Green:</u> Malachile Green - A.R. Grade (Sigma)

Ranocid Green Commercial - Commercial Grade

Direct Green'B' - Commercial Grade

Napthol Green - Commercial Grade

PLX - Green - A.R. Grade (BASF-Germany).

Studies on violet dyes indicated that the extent of increase in distillate output was dye specific rather than colour. This is in accordance with the expected behaviour (i.e. the optical absorption is a characteristic property of the molecule and varies from compound to compound, and is irrespective of similarity of colour). Experiments on different-green dyes were carried out with a view to confirm this observed behaviour. In an attempt above-mentioned five green dyes were selected randomly and productivity data for these dyes at different concentration/ water depths were taken. These data also confirmed the above observation e.g. the extent of increase in productivity was different for different dyes for a particular set of dye concentration/ water depth (e.g. 100 ppm/ 6 cm or 100 ppm/12 cm). It may be seen from the data, that the set 100 ppm/6 cm gave the best results for almost all the green dyes. It would not be out of place to mention that in view of the observed behaviour of black or blue dyes at higher concentrations and also the fact that large quantities of the dyes are required, dye concentrations above 100 ppm were not studied.

Among this group of dyes the performance of PLX-Green (supplied by C.S.M.C.R.I. Bhavanager) was found to be the best. Most of the work on this dye was done during the peak summer season (May and June 1981) a period when the performance of

the dyes, in general, was relatively poor (see section on seasonal study). A few observation on the performance of this dye need special mention that is:

a) This dye is quite stable, as is evident from the performance data (percent increase) on this dye for peak summer period, viz. May and June.

b) In view of the cost/benefit consideration, the performance of this dye for the set 50 ppm/6cm was found to be the best (increase being = 17%).

It may be mentioned that with the exception of a few dyes, reported here this dye was found to be the most suitable for use in large scale plants, (because of both its stability in sunlight and the smaller quantities required for increasing the still productivity). It may be mentioned that an equivalent of this dye is manufactured in the country by Atul Chemicals under the trade-name "SOLEVAP-GREEN".

(6) Red: Congo Red: (i) A.R. Grade.

(ii) Commercial Grade.

Garg and Mann (1976) reported that the use of even red colour also increased the distillate output (Table - III.1) However, as already mentioned no details as to the name or concentration of the dye used had been reported. In the absence of such information as well as the fact that red colour has least absorption in the visible region, a detailed study on this colour therefore was

undertaken. Initial experiments on one of the commonly available red coloured dyes (without any name) increased the distillate output by 8% for 1000 ppm dye concentration at 10 cm water depth, which was much lower than that obtained with the black dye under similar conditions (Sodha, Pandey and others, 1980). A detailed study on the above dye both A.R. and commercial grade) was, therefore, undertaken.

The concentrations studied were 50, 100 and 200 ppm at 6 cm and 50 ppm at 12 cm water depths. This dye was found to be quite stable in sun light.

It may be seen from the data (Table -III.5) that the relative performance of both the A.R. and Commercial grade dyes was similar. The best performance being at lower concentration as well as low water depths viz. 50 ppm/6 cm.

Such a good performance of this dye has no theoretical explantion in the light of existing theories. The only explanation for such a behaviour of this dye (as also other dyes) compared to commonly used black dye seems to be the fact that the black dye has highest absorption but the mechanism of release of absorbed (thermal) energy seems to play an important role in water distillation process. In other words the distribution of absorbed (thermal) energy by black (dye) molecules is multi-directional whereas in case of others corresponding distribution is undirectional i.e. the energy is released only in one direction in case

of red dye and is utilized effectively by the water surface for distillation whereas only a fraction of the energy, in case of black dye, goes towards the water surface (used for evaporation) and rest is distributed within the water. (The above mechanism has been suggested emperically).

In conclusion it may be mentioned that among the dyes studied, red dye was found to give the highest increase in distillate output for the set 50 ppm/6 cm. i.e. highest increase for the lowest dye input.

(7) Brown: Bismark Brown: A.R. Grade (Sigma).

The work on this dye did not have any theoretical basis except the unexpected behaviour of the red dye. The extent of increase, was not as good as that of red dye. It, however, was comparable to most of the other dyes studied. The dye, was found to be quite stable in sun-light.

III.b Studies on Some InorganicDyes:

The work so far reported was on organic dyes and the water used in the stills for distillation was tap water. However it was reasonable to expect that these dyes, though quite effective for solar water distillation, may not be so when used insaline water. The possibility of reaction of the dye (molecules) with the active constitutents of saline water in presence of sun light, leading to even decomposition of the dye, can not be ruled out. This is

further supported from observation reported earlier that the color of Methylene Blue when used in saline water started fading after a few days. The work, therefore, on inorganic dyes, which are relatively more stable was initiated. Since most of the experimental work planned had nearly completed only a preliminary study on few dyes namely - Potassium Permagnate ($KMnO4$, Magenta), Copper Sulphate Penta Hydrate ($CuSO_4.5H_2O$, light blue) and Potassium dichromate (K_2CrO4, yellow) was carried out (Table-III.3). These dyes were selected because of the following :

(a) these colors had not been studied earlier.

(b) these are commonly available cheap compounds; and

(c) these are well known herbicide/disinfectant.

The performance data on these dyes have been reported in Table-III.9 and shown in fig.III.4. It may be mentioned that as expected yellow color (K_2CrO4) did not give any positive response but, other two dyes gave their best performance for the set 100 ppm/6 cm. These data, however, are not enough to arrive at any conclusion on the use/performance of inorganic dyes in solar water distillation but indicate that a more detailed study specially with saline water is required to be undertaken.

<u>III.C Comparison with the reported data</u> :

The only work reported on dyes in literature other than this was that of Rajvanshi (1981) on three

TABLE III.9

STILL PERFORMANCE IN PRESENCE OF INORGANIC DYES

Dye	Concentration/ water depth (ppm/cm)	Distillate Output $1/m^2$ With dye	Without dye	Ratio	Per-cent in-crease	Remarks and Month and year of observation.
Potassium Permagnate (Majanta)						
	100/6	0.70	0.62	1.129	12.9	Dec. 81
	200/6	0.59	0.50	1.180	18.0	Dec. 81
	100/12	2.73	2.55	1.071	7.1	Jan. 82
	100/12 (Set I)	2.74	2.51	1.092	9.2	Jan. 82
	100/12 (Set II)	4.39	4.16	1.055	5.5	Feb. 82 (Rains)
Copper Sulphate (Light Blue)						
	50/6	0.50	0.50	1.000	-	Dec. 81
	100/6	0.66	0.55	1.20	20.0	Jan. 82
	100/6 (Set I)	0.60	0.51	1.176	17.6	Jan. 82
	100/6 (Set II)	1.00	0.89	1.124	12.4	Feb. 82
	100/6	1.03	0.93	1.103	10.8	Mar. 82
	100/6	1.38	1.23	1.122	12.2	Mar. 82
Potassium Chromate (Yellow)						
	50/6	0.51	0.48	1.063	6.3	Dec. 81
	100/6	0.59	0.54	1.093	9.3	Jan. 82
	100/6	0.60	0.51	1.176	17.6	Jan. 82

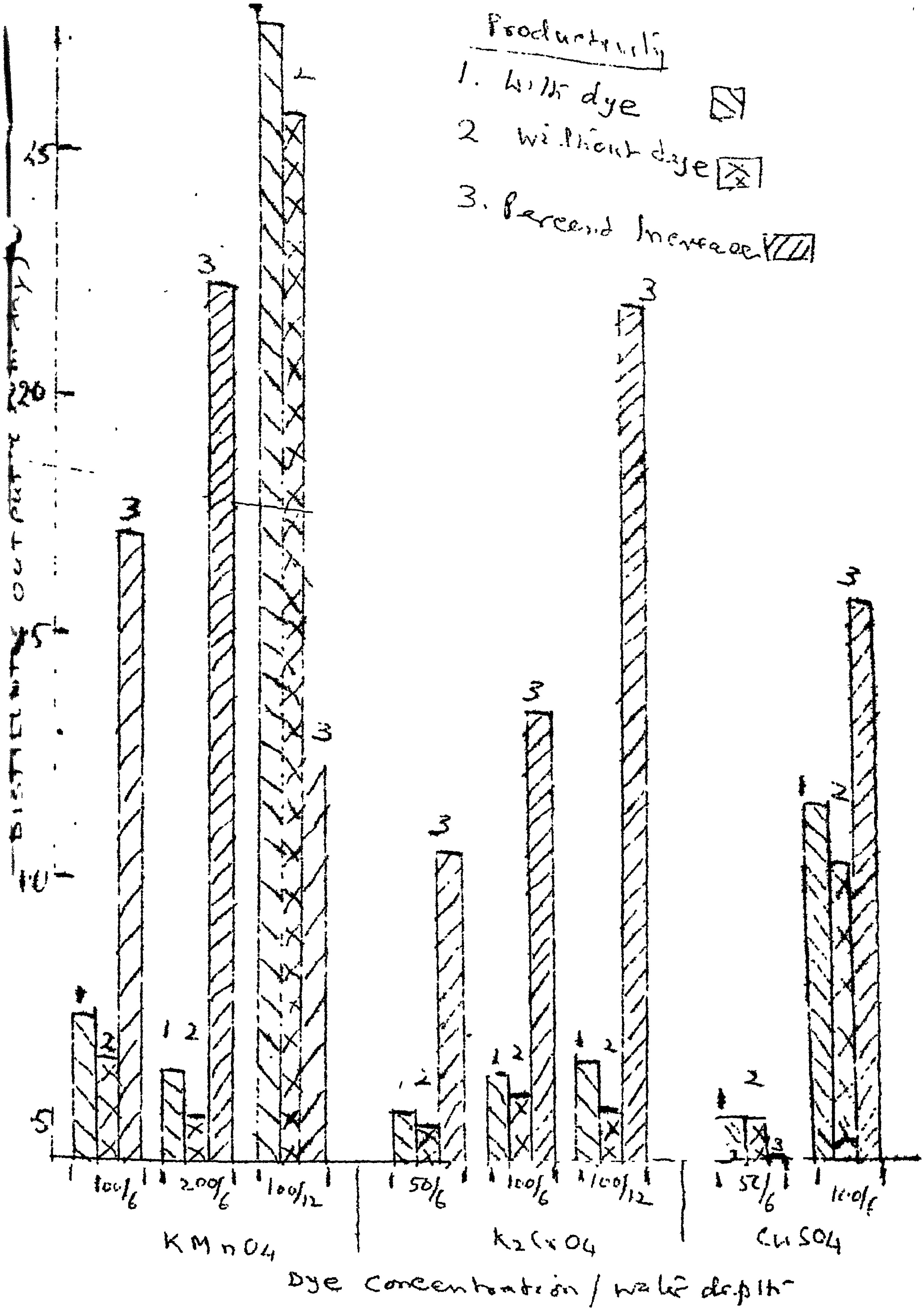


Fig. III.4 Performance of Inorganic

TABLE-III.10

COMPARISON WITH THE REPORTED DATA

Sl. No.	Colour/ Dye	Dye Concentration (in ppm)	Percent increase in output	Remarks and Reference
A.	Red			
1.		50	7.4	1
2.		50	30.0	2 (AR)
3.		50	33.7	2 (Comm)
4.		100	19.9	1
5.		100	12.9	2 (AR)
6.		100	26.8	2 (Comm)
7.		-	25.25	3
B.	Black			
8.		50	15.9	1
9.		100	11.6	2 (Comm)
C.	Green			
10.		50	14.8	1
11.		50	15.0	2 (PLX-Green)
12.		100 100	12.0 20.1	1 2 (PLX-Green)
D.	Blue			
13.		-	14.4	3
14.		100	18.3	2 (AR)

1. Rajvanshi, A.K., Solar Energy, 27, 51 (1981)
2. Present Work (Table-III.5, data for 6 cm. water depth)
3. Garg, H.P. & Mann, H.S., Solar Energy, 18, 159 (1976).

dyes representing different colors viz. red, black and green. Since the dyes used in the present study were different from those used by him, corelation of these data, therefore, was not possible. However, a comparative account of the performance of different colors (data reported in Table-III.4( )showed that :

(i) the use of dye increased the distillate output.

(ii) there was no correspondence between the concentration of the dye and the percent increase in distillate output.

(iii) in almost all the cases, the performance of a color at a particular concentration was nearly the same with the exception of a few.

These observation, in addition, to confirmation of the present data, also showed the utility of this work.

III.d <u>Effect of Seasonal Variation on the Performance of Dyes</u> :

During the course of this work it was observed that the still productivity is dependent upon a number of parameters, some of these are :

(1) For no insulation beneath the still the distillate output has little dependence on water depth but in case of insulated stills it plays an important role.

(2) The use of double glass cover markedly reduces the output in practical installations.

(3) For maximum distillate output, optimum inclination of glass cover varies from place to place (between 10° - 20°).

(4) The distillate output falls linearly and slowly as the salt concentration of the brackish water increases.

(5) Higher wind velocities give slightly higher oupu output although above 8 km. p.h., this increase is very small.

(6) Lower ambient temperatures reduced the output.

(7) The output can be improved by increasing water temperature and/or the difference in temperatures of the water surfance and the glass cover.

These variations (specially 5 to 7) indicate that the performances of a dye may be affected with the change in season and thus indicated the necessity of studying the performance of the dye on annual basis rather than a few observation.

In addition, this study may also provide information/data on

(a) the annual and periodic performance of the dye; and

(b) identification of the months/periods when the performance of the dye was poor.

These informations as a whole are quite useful for

(i) calculation of average percent increase in distillate output.

(ii) the exclusion of months/periods when the performance of the dye was poor.

(iii) long-term utilization of a dye in solar stills vis-a-vis increase in distillate output.

Two dyes, namely Diphenyl Black and Methylene Blue were selected arbitrarily for seasonal study. The data on these dyes were collected for a period of about 2 years on monthly basis. The monthly data, reported, represent the average of 8-10 days distillate output in a month. It may be mentioned that for seasonal study the black dye from two different lots and blue dye from 3 different sources were used, the details of which have been given alongwith the data in Tables-III.11 and III.12 respectively. The seasonal performance has been shown in figure-III.5, as the percent increase in distillate output versus monthly data collection for both the dyes. The still productivity with and without dye has been given in figures-III.6 and III.7 for black and blue dyes respectively.

An observation of the data on both the dyes, indicates that, as expected, the monthly performance data are not reproducible after a year, but as is evident from figures-III.6 and III.7, the nature of the annual performance curves is similar for both the dyes. Another observation worth mentioning is that the extent of percent increase in distillate output showed a decline during summer months which could be due to

TABLE_III.11

AVERAGE MONTHLY PERFORMANCE OF THE STILL IN PRESENCE OF DIPHENYL BLACK*

Sl. No.	Year	Month of observation	Average Distillate output ($1/m^2$ day) With dye	Without dye	Ratio	Percent increase
SET I						
1.	1980	January	1.60	1.41	1.135	13.5
		February	1.55	1.34	1.157	15.7
		March	2.33	1.99	1.171	17.1
		April	-	-	-	-
		May	3.14	2.93	1.072	7.2
		June	2.89	2.61	1.107	10.7
		July	2.43	2.08	1.168	16.8
		August	2.35	2.22	1.059	5.9
		September	2.34	2.18	1.073	7.3
		October	1.78	1.54	1.156	15.6
		November	-	-	-	-
		December	-	-	-	-
SET II	Average (Jun 81 to Oct 81)		2 27	2.03	1 118	11 8
2.	1981	January	-	-	-	-
		February	-	-	-	-
		March	2.11	1.95	1.082	8.2
		April	2.25	2.02	1.114	11.4
		May	2.71	2.51	1.080	8.0

contd.. . 2/...

Table-III.11 contd...

Sl. No.	Year	Month of observation	Average Distillate output (1/m^2 day)		Ratio	Percent increase
			With dye	Without dye		
	1981	June	2.93	2.59	1.131	13.1
		July	-	-	-	-
		August	-	-	-	-
		September	-	-	-	-
		October	1.72	1.59	1.082	8.2
		November	1.50	1.42	1.056	5.6
		December	1.16	1.08	1.074	7.4
		Average (March-Dec 81)	2.05	1.88	1.090	9.0
	1982	January	1.26	1.15	1.096	9.6
		February	1.00	0.93	1.075	7.5
		March	1.46	1.33	1.098	9.8
		April	2.36	2.12	1.113	11.3
		Average (Jan.-April 82)	1.52	1.38	1.102	10.2

* (i) Sets I & II represent performance data on the dye purchased from two different lots.

(ii) Dye concentration/water depth = 100 ppm/12 cm.

(iii) Months when data could not be collected either due to rains or otherwise, have been indicated by -

TABLE_III.12

AVERAGE MONTHLY PERFORMANCE OF THE STILL IN PRESENCE OF MYTHYLENE BLUE*

Sl. No.	Year	Month of obser-vation	Average Distillate Out-put($1/m^2$ day)		Ratio	Percentage increase
			with dye	without dye		
SET I		Mythylene Blue (A.R. Grade - Sigma)				
1.	1980	May	3.41	3.09	1.104	10.4
2.		June	2.66	2.45	1.086	8.6
3.		July	2.34	1.91	1.225	22.5
4.		August	1.73	1.46	1.185	18.5
5.		September	2.17	2.09	1.038	3.8
6.		October	2.15	1.91	1.126	12.6
7.		November	1.37	1.17	1.171	17.1
8.		December	-	-	-	-
9.	1981	January	-	-	-	-
10.		February	-	-	-	-
11.		March	2.19	2.02	1.084	8.4
12.		April	2.31	2.12	1.090	9.0
13.		May	2.85	2.45	1.163	16.3
		Average (May 80-May 1981)	2.32	2.07	1.120	12.0
SET II		Mythylene Blue (AR -Grade, Lobo Chemicals)				
14.	1981	June	2.23	2.12	1.052	5.2
15.		July	-	-	-	-
16.		August	-	-	-	-
17.		September	-	-	-	-
18.		October	1.86	1.72	1.081	8.1
19.		November	1.38	1.26	1.095	9.5
20.		December	0.93	0.86	1.081	8.1
		Average				

Table-III.12 contd...

Sl. No.	Year	Month of observation	Average Distillate Out-Put ($1/m^2$ day) with dye	without dye	Ratio	Percentage increase
SET III		Mythylene Blue (Commercial grade)				
21.	1981	October	1.66	1.26	1.317	31.7
22.		November	1.37	1.22	1.123	12.3
23.		December	0.91	0.84	1.083	8.3
24.	1982	January	0.96	0.90	1.067	6.7
25.		February	0.98	0.90	1.089	8.9
26.		March	1.46	1.34	1.089	8.9
27.		April	2.30	2.07	1.111	11.1
		Average (Oct. 81 - Apr. 82)	1.38	1.22	1.131	13.1

* (i) Dye Concentration/Water depth = 100 ppm/12 cm.

(ii) Months when data could not be collected either due to rains or otherwise have been marked - .

(iii) These data have not been included in figure III.3.

(iv) Data at Sl. No. 21-23 have not been included in the figure to avoid repeatation/occasional rains during the p eriod of data collection.

Occasional rains during the period of data collection.

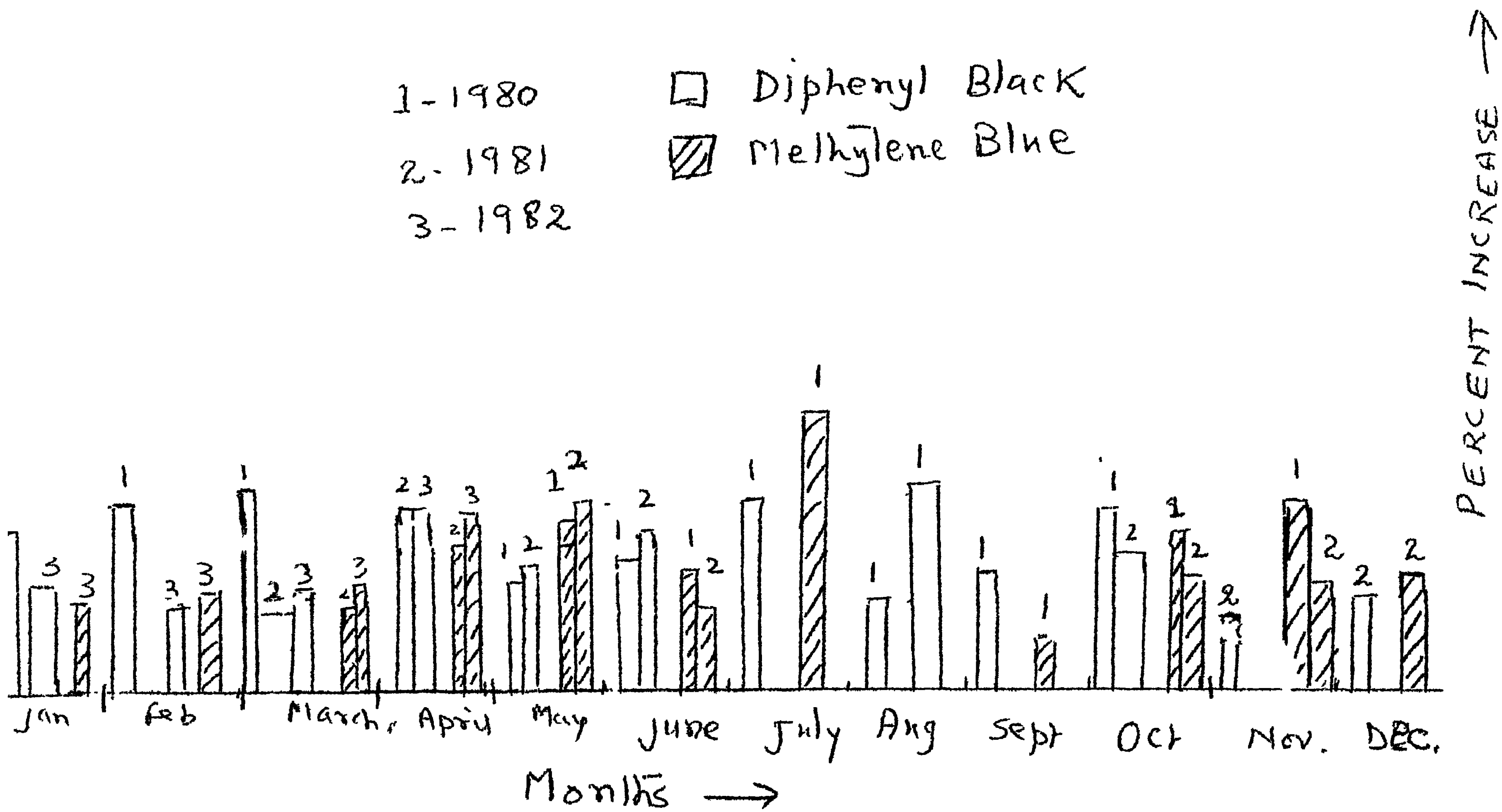


Fig III.5 Seasonal Performance of dyes.

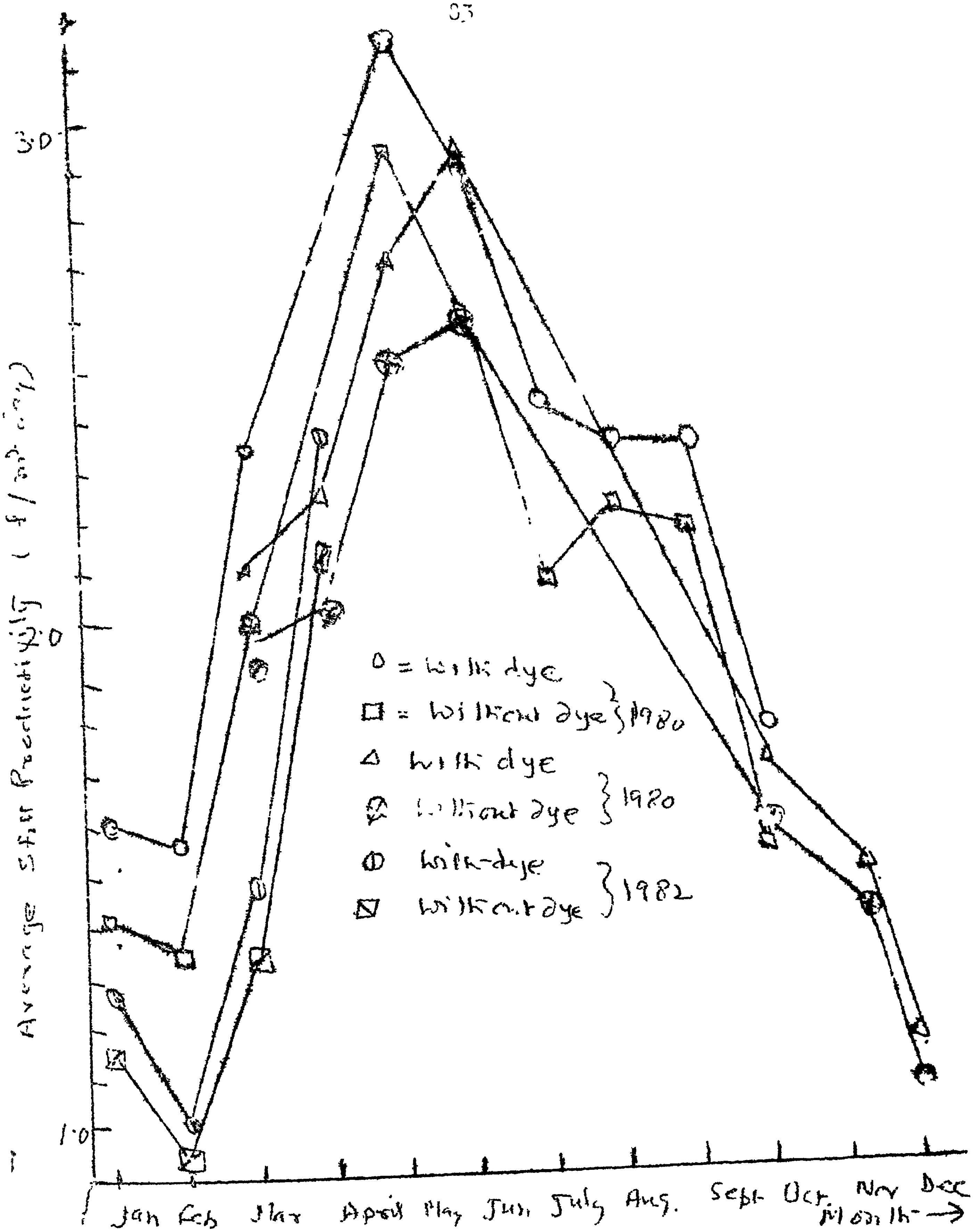


Fig III.6: Effect of Seasonal variation with Black dye.

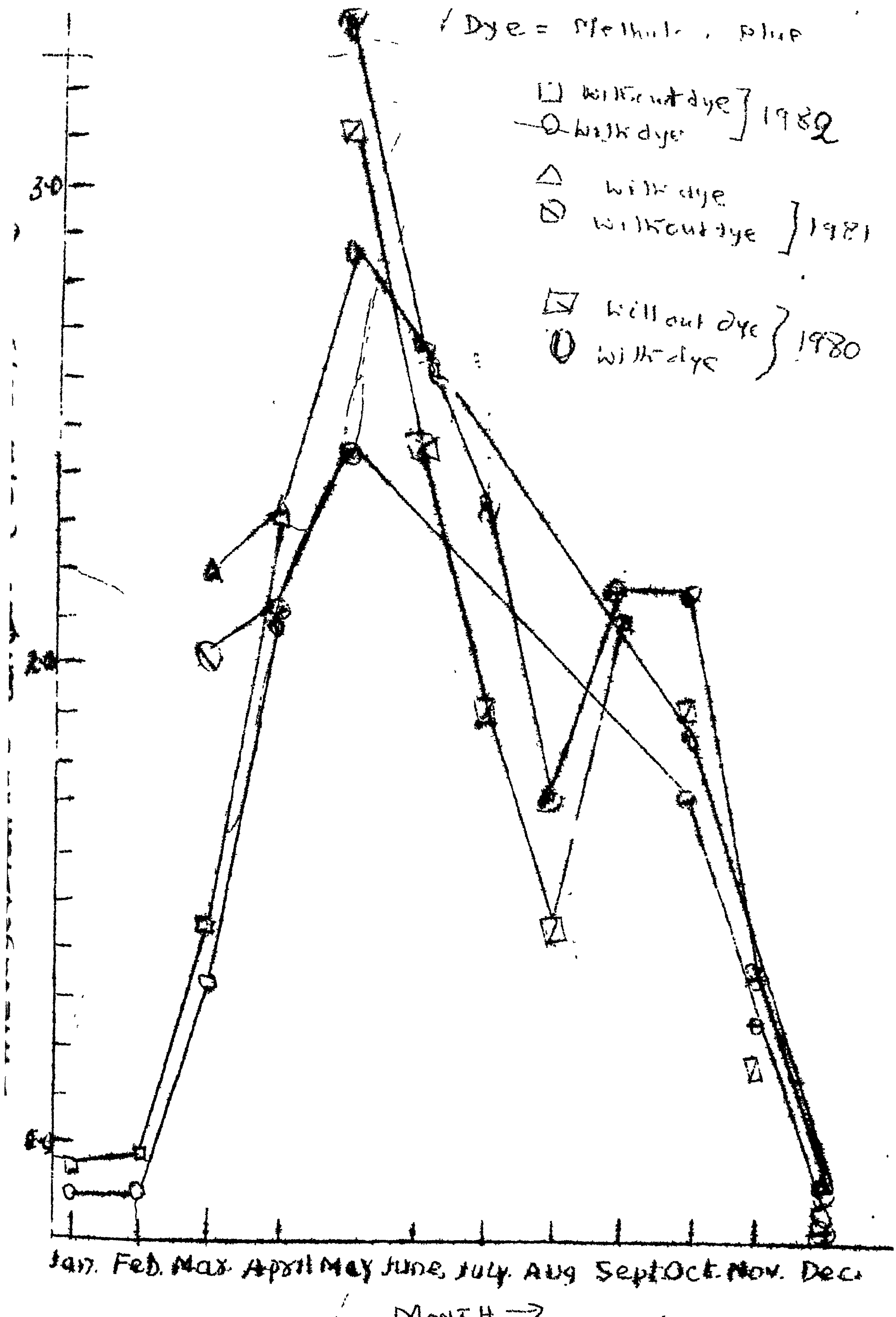


Fig III.7 Seasonal Var...

instability of the dye in sun light at higher ambient temperatures. The data during the periods of rains could not be collected (even when collected were neither consistent nor reliable) and account for the absence of data during some of the months.

III.e Effect of Dyes in Large Solar Stills (Field Performance):

The data on the effect of dyes presented in the preceeding section show the performance of the dye in a small still. The use of dye in large stills, in addition to increasing distillate output, also has the advantage that the water surface in the still always remains colored. This, in turn, reduces the cumbersome job of frequent cleaning of the deposited salt as well as painting of the bottom of the still basin. This, while saving the cost of both the paint and manpower, allows continuous operation of the still.

One of the dyes -Methylene Blue was selected for performance studies on a large still. The data on both A.R. Quality and Commercial grade dyes were taken at one of the large solar distillation plants of Central Salt & Marine Chemicals Research Institute, Bhavnagar at Awania village, which supplies drinking water to the local inhabitants. The observations on A.R. and Commercial grade dyes were taken in February/March 1981 and March/April 1982 respectively. The distillate output data during the day time performance (8 am - 6 pm) :

in presence of A.R. grade Methylene Blue (as sent by C.S.M.C.R.I., Bhavnagar) have been reported in Table-III.13. Following observations have also been reported (Gomkale, personal communication);

(i) the dye used to become ineffective after 4-5 days as also indicated by fading of the blue colour of the water. This seems to be due to possible decomposition of the dye in saline water in presence of sunlight.

(ii) the day time performance of the A.R. grade dye was quite good, (relative increase being as much as 58%), however, overall 24 hour performance was not so (relative increase being about 6-8%). This unusual behaviour could not be explained in the absence of any details on various parameters like temperatures, insulation, etc.

(iii) the corresponding day time increase in distillate output with the commercial grade dye was somewhat lower ($\leq$ 40%).

(iv) the performance data of the same dye (commercial grade) on smaller stills at C.S.M.C.R.I., Bhavnagar was nearly similar to that reported by us.

In addition to these, recently Venkatraman et al., (1982), reported their studies on one of the black dyes (details not given) and have shown that

TABLE-III.13

PRELIMINARY DATA ON THE PERFORMANCE OF LARGE SOLAR STILL IN PRESENCE OF BLUE DYE

Sl. No.	Date of observation	Concentration (ppm)	Water-depth (cm)	Distillate Output (P)		Percent increase
				with dye	Without dye	
1.	March 2, 1981	70	4	26.5	16.8	57.7
2.	March 3, 1981	70	4	28.3	17.9	58.1
3.	March 4, 1981	70	4	27.0	17.7	52.5

Hourly data for the period 8 a.m. - 6 p.m. were taken in Still having 2000 ltrs. raw water capacity.

the presence of dye increased the still productivity by about 30%. This study also supports the fact the use of dye increases the distilled water production.

∴ In the light of above observations, it may be concluded that the presence of dye increases the productivity (due to reduced reflection losses and greater absorption of sunlight) during the day.

OBSERVATIONS / CONCLUSION

Some of the important observations of this work are:

(1) Distillate output increases with the increase in the concentration but does not follow any regular trend.

(2) At lower water depths the effect of dye was insignificant.

(3) The performance was dye specific rather than colour specific, eg., green and violet dyes.

(4) Some of the dyes (Blue, Black, BASF Green, Bismark, Brown) were found to be fairly stable in sunlight.

(5) Dye concentration should be decided on the basis of cost/benefit analysis and the percent increase in distillate output.

(6) Preliminary data on inorganic dyes showed that a detailed study is required specially with regard to their use in the distillation of saline water.

(7) Seasonal performance data indicated that the extent of increase in productivity due to dye, in general, is reduced during summer months.

(8) Barring a few months, deviation in the extent of increase in productivity, was not too large. from the annual average value.

(9) The presence of dye in large distillation plants (field trials) also showed an increase in distillate output. However, possible instability of specially organic dyes in saline water (due to photo decomposition in presence of active constituent of the saline water) will have to be tested for individual dyes.

CHAPTER-IV

EFFECT OF SURFACE AREA ON THE PERFORMANCE OF SOLAR STILL

Summary

This chapter deals with the results of preliminary studies on the effect of surface area on still productivity. Effect of floating coal and colonisation of brackish water have also been included. The data show an increase in still productivity in both the cases specially at low water depths.

In the present chapter work on the effect of increasing the surface area on the performance of still has been discussed. The work reported deals with the following :

(a) Effect of Colonization of raw water into long and cross channels;

(b) Effect of floating coal on the water surface; and

(c) Effect of presence of dye on (a) and (b).

Experimental:

Single sloped basin type solar stills made of aluminium (0.5 m x 0.5 m) encased in a wooden box insulated by glass wool (3 cm thickness) were used for the experiments. The cover angle was kept at 12°. The data were taken, after 3-4 days i.e. after the transient phase, for a minimum 5-6 days. The per cent increase in productivity has been calculated by averaging consistent data only. Hourly data on temperature , solar insolation, productivity etc., were taken to see the distillation behaviour of the still.

The channels made of aluminium were evenly spaced at 3 cm intervals, length and height being 47 cm and 6 cm respectively were placed at the basin such that the water level did not cross the channel walls. There

were as many as 17 channels in the still. Cross channels were similar to that of the long channel except that there were squares of 5 cm^2 area.

The experiments on floating coal were done by placing a gauze fixed on a hollow pipe frame which enabled it to remain floating on the water surface. The coal pieces were kept on the gauze. The water depth was maintained such that the coal pieces were just in contact with the underlying water.

Studies on two dyes, black and blue black, were done both separately (data reported in Chapter-III) as well as in presense of channels and floating coal. The dyes were dissolved in raw water and kept in the still at the required water depth

Results and Discussion:

The solar water distillation is a surface phenomenon and its effectiveness is determined by two important conditions viz. larger temperature difference between the water surface and glass cover, as well as the surface area, favouring the distillation process. The energy input in a single effect solar distillation system is equal to the total heat of vaporisation of water, however in the absense of information on the heat lost in condensetion restricts overall calculation of energy balance. The rate of distillation, can

be determined by relationship:

$$\text{Rate of Distillation} = \frac{\text{Incident Solar Energy (K cal/m}^2\text{ day)}}{\text{Latent Heat (Cal/gm)}} \times \text{Collector Efficiency}$$

Thus the collector efficiency of the still, which is governed by raw water/black bottom, determined the performance of the still. The present work deals with the improvement in the (raw) water collector efficiency of the still by increasing the surface area.

A. Effect of Channel:

The colonisation of raw water increases its surface area. The observations at 4 and 6 cm depths have been reported in TableIV.1. The data indicate that the pressure of long channel in the stills increases the distillate output by about 20% at 6 cm which increases further at lower depth.

The cross channels, though expected to provide larger surface area compared to long channels did increase the productivity (13.5%) but to a lesser extent which seems to be due to leakage that may have developed in the still after the channels were placed.

B. Effect of Floating Coal:

Akinsate and Doru(1979) have reported their results on the effect of coal at low water depths, the coal pieces being kept on the bottom of the

Table-IV.1

Effect of Channel on still productivity

Set No.	Water Depth cm	Output in l/m^2 day With Channel	Output in l/m^2 day Without Channel	Percent Increase
A - Long channels				
I	6	1.41	1.17	21
	6	1.35	1.10	23
	6	1.37	1.13	20
	6	1.35	1.10	23
	6	1.75	1.46	20
	Average Increase = 21.4%			
II	6	1.44	1.19	21
	6	1.48	1.25	18
	6	1.71	1.42	20
	6	1.59	1.37	16
	Average Increase = 18.75%			
	Average of Set I & II = 20%			
III	4	0.53	0.52	2
	4	1.22	0.97	26
	4	1.53	1.20	27
	Average Increase = 26.5%			
B - Cross channels				
IV	6	1.59	1.42	12
	6	1.95	1.72	13
	6	1.71	1.51	13
	6	1.33	0.90	40*
	Average Increase = 13%			

* Data marked * have not been taken in calculation of average value.

still(i.e.coal pieces providing the black surface). T data given by them indicate that the productivity increases difectly with the incident solar energy.

The present work was undertaken with a view to study the effect on still productivity when coal is kept floating just above the water surface special at higher water depths and whether presense of dye has any effect on the performance of the still.

As is well known, the coal has a dual property i.e. it provides a good black surface for absorption of incident solar energy as well as large surface area, thereby increasing the rate of evaporation from its surface.

The results reported in Table-IV.2 indicate that in the small solar still at 6 cm depth the productivit increases by about 25%. The experiment, when repeated during summer, the still performance was found to be the same indicating that the relative absorption/ evaporation process was not affected by season. An observation of figure-IV.1 which gives hourly data on productivity both with and without floating coal, sh that though the floating coal allows heat storage, during the day but the extent of release of this store

Table IV.2

Output in solar still containing floating coal with and without dye

Set No.	Water depth (cm)	Output in l/m^2 day with floating coal	Output in l/m^2 day without coal	Percent increase (%)
A- Effect of Floating Coal				
I (water)	6	1.50	1.42	5
	6	1.71	1.40	22
	6	0.78	0.68	14
	6	1.69	1.25	35
	Average Increase = 23.8 %			
Repeat				
II	6	3.28	2.56	28
	6	3.43	2.56	24
	6	2.84	2.56	11
	6	3.43	2.58	32
	Average Increase = 24 %			
B- Effect of Floating Coal in presence of black dye (Concentration = 500 ppm)				
*III (Water + dye)				
	6	1.44	1.08	33
	6	0.68	0.55	23
	6	1.15	0.90	27
	6	1.25	0.90	30
	6	1.31	1.011	30
	Average Increase = 28.6 %			

*Third column represents still productivity with floating coal in presence of dye, whereas fourth column represents output without floating coal and the dye (reference). The increase due to black dye for the set 500/6, was found to be 4.7% (Table-IV.3).

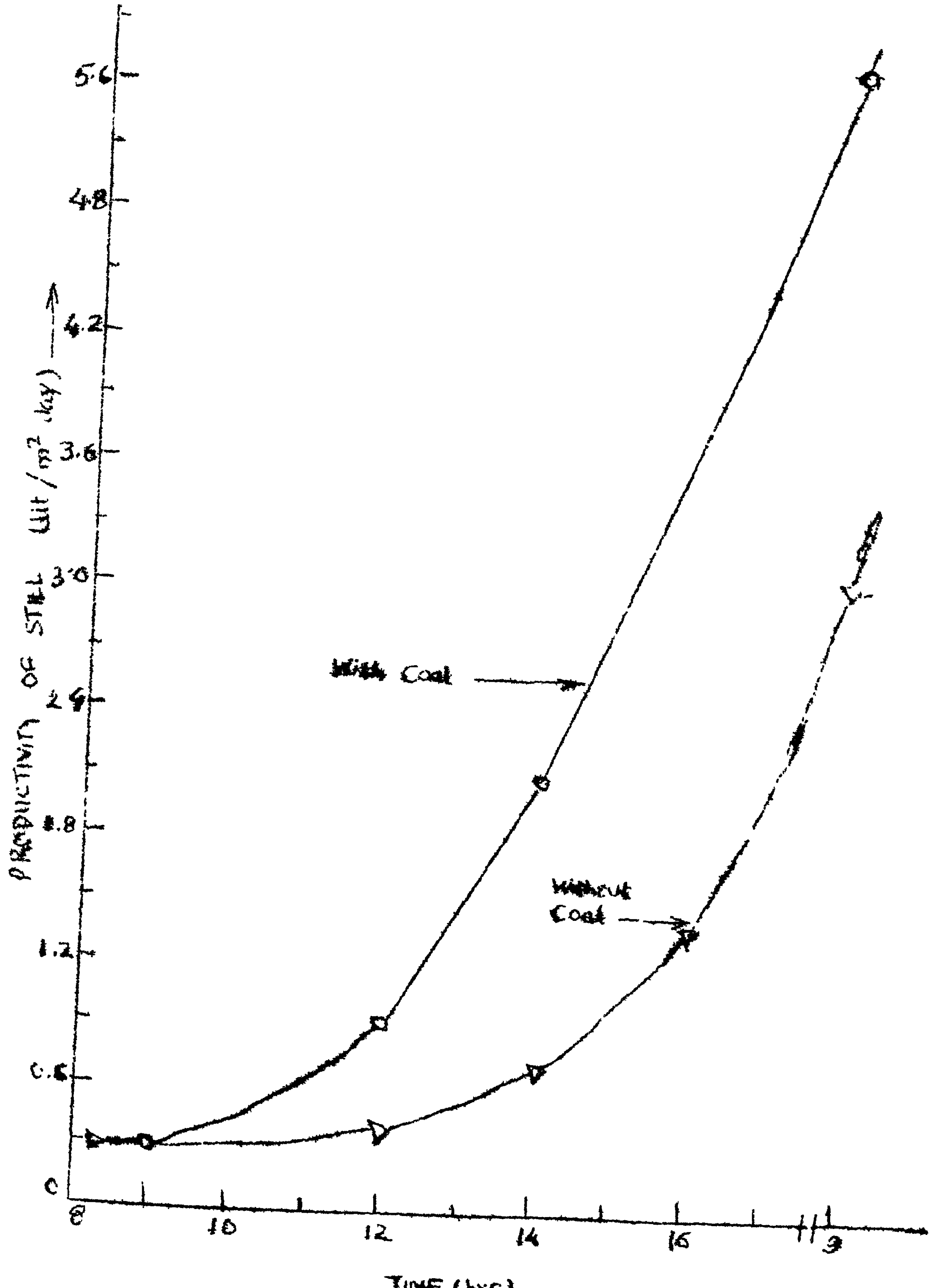


Fig. E1 EFFECT OF FLOATING COAL ON HOURLY VARIATION IN STILL PRODUC

energy evaporation seems to be relatively low (though better than without coal). The possible reason for this behaviour could be that during night the overlying coal(being a bad conductor of heat) acts as a cold surface (relative to underlying raw water which is hot) and thus the condition of large temperature difference is not satisfied as a result the output during night was much lower than expected. However, considering over all performance, the floating coal increases the efficiency of the still leading to higher productivity. A detailed study is recommended.

C. Effect of Dyes:

During the course of our studies on the effect of dye on still productivity, black and blue black dyes were found to have given good result (Sodha et al., 1980, 1981 and 1983 also table III 5. It was therefore, decided to study the combined effect i.e. dye mixed water in stills having floating coal or channels. The results have been reported in Tables-IV.2 and IV.3 respectively. Though an increase in still productivity has been found in all the cases but following observations need special mention:

(1) There is a great irregularity in the daily output obtained (even for 4-5 days) in case of floating coal which supports the mechanism suggested for the evaporation process in the still.

TABLE-IV.3

Effect of dye in presence and absence of channel at 5 cm water depth

Set No.	Concentration of dye	Output in l/m^2 day With Channel +Dye	Output in l/m^2 day Without Channel +Dye	Percent Increase	Corresponding increase in absence of a channel
A - Long channels					
I	Black 500 ppm	0.76	0.62	22	
		1.26	0.91	33	
		1.62	1.27	27	4.7%
		1.90	1.58	20	
		2.07	1.76	17	
		1.59	1.39	14	
	Average Increase = 23%				
II	Blue Black 100 ppm.	0.96	0.72	33	
		1.00	0.80	25	
		1.20	0.97	23	
		0.89	0.73	22	
		2.73	2.23	22	
	Average Increase = 25%				
B - Cross Channel					
III	Black Dye 100 ppm	1.02	0.58	20	
		0.38	0.34	11	
		0.91	0.78	16	
		1.24	1.08	15	
		0.88	1.00	--	
		1.15	1.22	--	
		1.66	1.39	11	
		1.37	1.32	4	
	Average Increase = 16.2%				

* Data marked * have not been taken in calculation of average value.

(2) A comparison of data (Table IV.1 and IV. 3) on the effect of (long) channel+dye (for two dyes) showed that the extent of increase due to dye + channel follows the emperical relationship:

$$P_{(c+d)} = P_c + P_d - 2$$

Where:

$P_{(c+d)}$ = Percent increase due to channel+dye

P_c = Percent increase due to channel

P_d = Corresponding percent increase due to dye alone.

This preliminary study indicates that the still performance is improved by increasing the surface area, however, lower water depth is recommended. The dye gives only an additive increase in case of stills with long channels.

CHAPTER-V

EFFECT OF DRIED AND FORCED AIR BUBBLING ON THE WATER VAPOUR PRESSURE AND THE PERFORMANCE OF SOLAR STILL

Summary

The results on the performance of solar still with the following objective;

(i) .Effect of bubbling ambient air

(ii) .Effect of stirring brackish water

have been reported in this chapter.

A study on the effect of bubbling ambient air and stirring the brackish water on the performance of the solar stills was undertaken. The results obtained during the course of this study have been reported in this chapter. The discussions have been arranged under following two sections;

A. Bubbling of ambient air

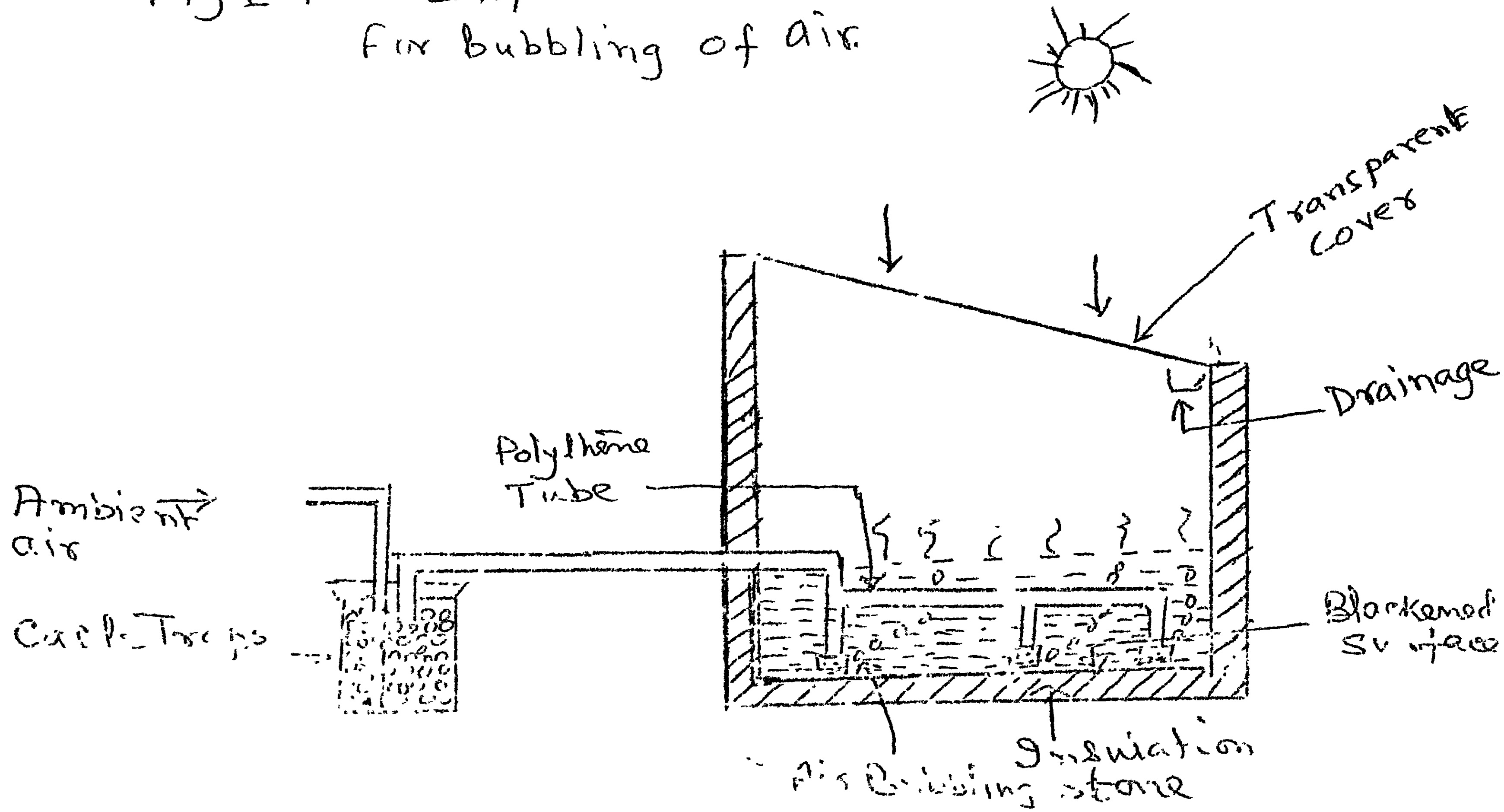
B. Stirring of Brackish water

The details of each of the above methods have been given below:

A. <u>Bubbling of ambient air</u>

The experimental set up as shown in figure-V.1, consisted of a solar still having an effective basin area of 0.6864 m^2, made of galvanised iron sheet and in cased in a wooden box. About 4cm. thick insulation of glass wool was provided between the basin and the wooden box. The vertical heights of the basin were 29cm and 15cm with a slope of 10^0 with respect to the horizontal surface. The basin of the still

fig V.1 Experimental setup for bubbling of air



was painted black. A 4 mm thick glass was mounted on the basin with the help of frame. Whole assembly was made air tight with the help of rubber gaskets. A polythene tube was placed in the (brackish) water through the inlet, and was provided branch connections with the help of glass connectors in order to cover the maximum basin area under water. The ends of these branches were then connected to the main tube for bubbling of ambient air by means of a pump. The rate of bubbling was adjusted by trial and error in a way such that sufficient time was available for bubbles to absorb water molecules (to be referred as aquation of air in the text) befo e leaving the water surface in the still. The drying of ambient air was done by placing Calcium Chloride traps in series, between pump and the still. The cooling of the glass surface was achieved by flowing water (under gravity) from upper side of the glass cover. Ten litres of water was taken in the still.

Another still having similar dimensions and under similar experimental conditions was taken as reference still for comparative performance of the experimental still. A correlation between the experimental and reference still was determined before the experiment, to ensure similar performance of both the stills. Any variation due to, for

instance, leakage could thus be accounted for.

The performance of the experimental still has been reported in terms of percent increase in distillate output with respect to the reference still.

Results and Discussions

In any evaporation process, neglecting salt deposits on the free surface, there are three processes by which mass transfer occurs- viz.; (i) transfer of those molecules which possess the required energy to pass through the liquid/gas boundary to gas/liquid boundary. In case of water, for example nearly 10% of liquid modecules have the necessary energy to escape from the liquid phase.

(ii) Another process, which is quite rapid is the mass transfer of these active molecules across the interface.

(iii) Removal of molecules which have now appeared in the gas phase away from the interface and into the bulk of the gas.

In solar still , the first process controls the overall distillation rate. The process of bubbling of ambient air through brackish water is expected to alter the two transfer rates governing (a) the transfer of molecules to the free surface and (b) the removal of transferred molecules from free surface to the bulk gas phase. Such variations showed an increase in the distilled water

production in solar stills.

The results obtained during the course of following sets of experiments:

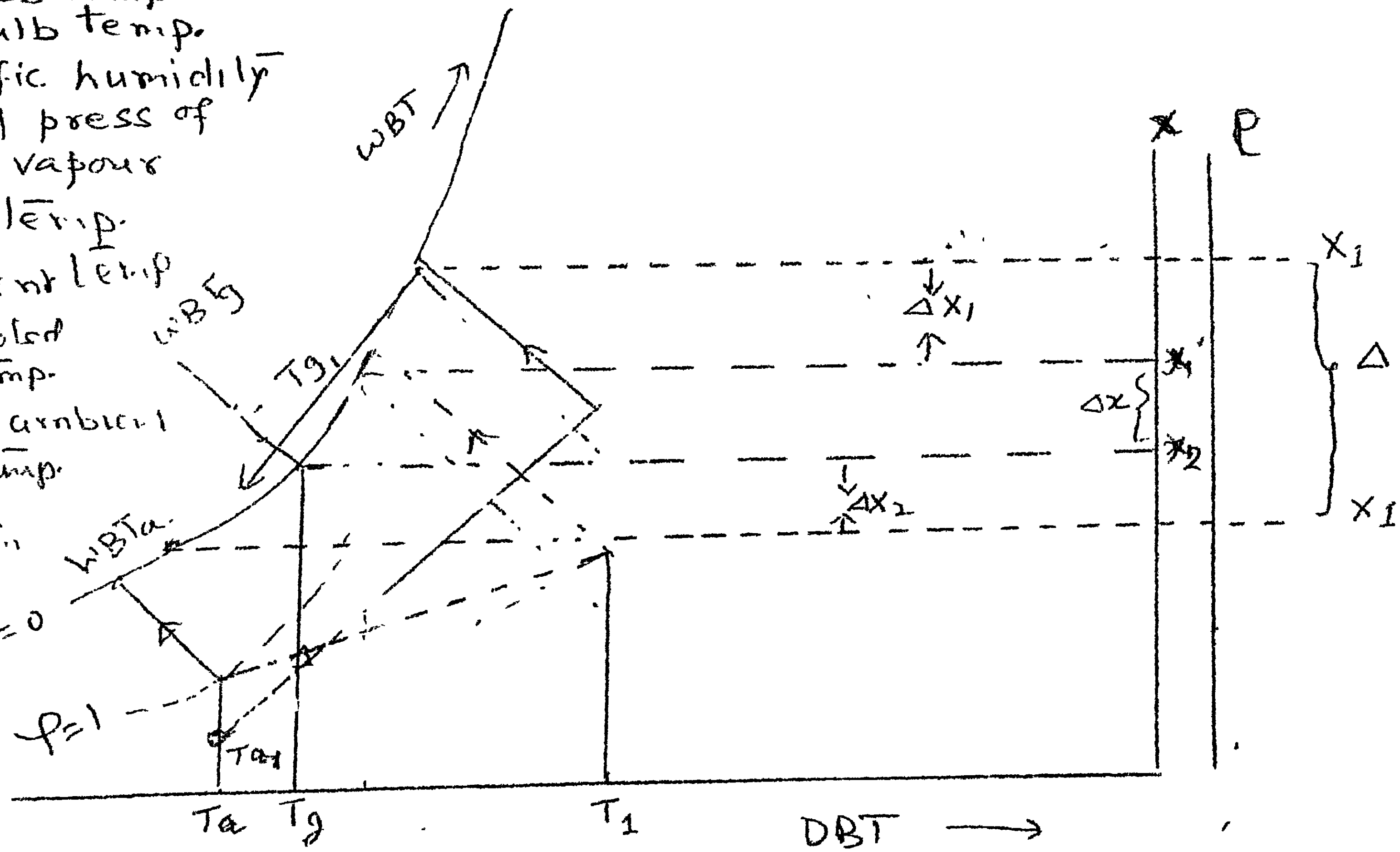
1. Bubbling of water(to be distilled) with ambient air.
2. Bubbling of water(to be distilled) with dry ambient air (i.e., after passing through $CaCl_2$)
3. Bubbling of dry ambient air + Cooling of glass surface.
4. Cooling of surface,

have been discussed below.

The distillation process indicating condensation effects due to dry air bubbling and water cooled glass surface has been shown on psychrometric chart (figure -V.2).

Experiments were done during the period when humidity of the ambient air was neither too low nor too high. The first experiment was done by bubbling of ambient air through the brackish water. The data reported in Table-V.1 showed that a marginal increase of about 6-7% was obtained over a 24-hour period. The hourly performance data plotted in figure -V.3 indicate that the rate of distillation in the experimental still was slightly higher compared to reference, except for a short period in the afternoon when bubbling gave much higher distillate output. This could be explained on the basis that in the afternoons, due to increased solar radiation (and also ambient temperature) the humidity in

DBT : Dry bulb temp.
X : Specific humidity
ρ : Partial press of water vapour
Tg : glass temp.
Ta : Ambient temp.
Tg1 : water cooled glass temp.
Ta1 : Dried ambient air temp.
Improved Distillation cycle
Reference distillation cycle.



ΔX_1 : Condensation effect due to dry air bubbling
ΔX_2 : condensation effect due to water cooled glass surface

Fig V.2 DISTILLATION PROCESS ON PSYCHROMETRIC CHART

Table-V.1

Performance of Solar Still with Bubbling of Ambient Air (Water Depth 4 cm).

Date & time of observation IST, Hours	Time of Bubbling in minutes	Distillate output in $1/m^2$ day: with Bubbling	Distillate output in $1/m^2$ day: without Bubbling	Ratio	Solar Intensity in W/m^2	Temperature (°C): Ambient	Temperature (°C): Water: With Bubbling	Temperature (°C): Water: Without Bubbling
0700	0	0.0	0.0	0	0	0	0	0
0800	50	.0146	.0217	1.15	22	27	26	26
0900	45	.0219	.0140	1.56	43	30.2	31	28
1000	45	.0131	.0122	1.07	58	33.2	37	34
1100	55	.0072	.0102	0.71	68	34	43	42
1200	55	.0291	.0255	1.14	72	34.6	48	50
1300	50	.1457	.1251	1.16	69	36.4	53	56
1400	40	.2360	.2133	1.11	63	36.3	57	58
1500	40	.2579	.2356	1.09	46	35.0	55	49
1600	45	.2331	.2113	1.10	24	33	52	56
1700	50	.2229	.2215	1.00	8	31	48	52
1800	50	.2010	.1869	1.07	2	31	43	46
1900	50	.1486	.1498	0.99	0	29	39	41
2000	40	.1034	.0988	1.04	0	28.4	36	38
2100	45	.0758	.0704	1.07	0	27	33	34
2200	45	.0597	.0525	1.14	0	26	31	31
0700	-	.2112	.2087	1.01	5	-	-	-
Total (24 hrs)		1.981	1.849	1.071				

Average Increase = 7.1%

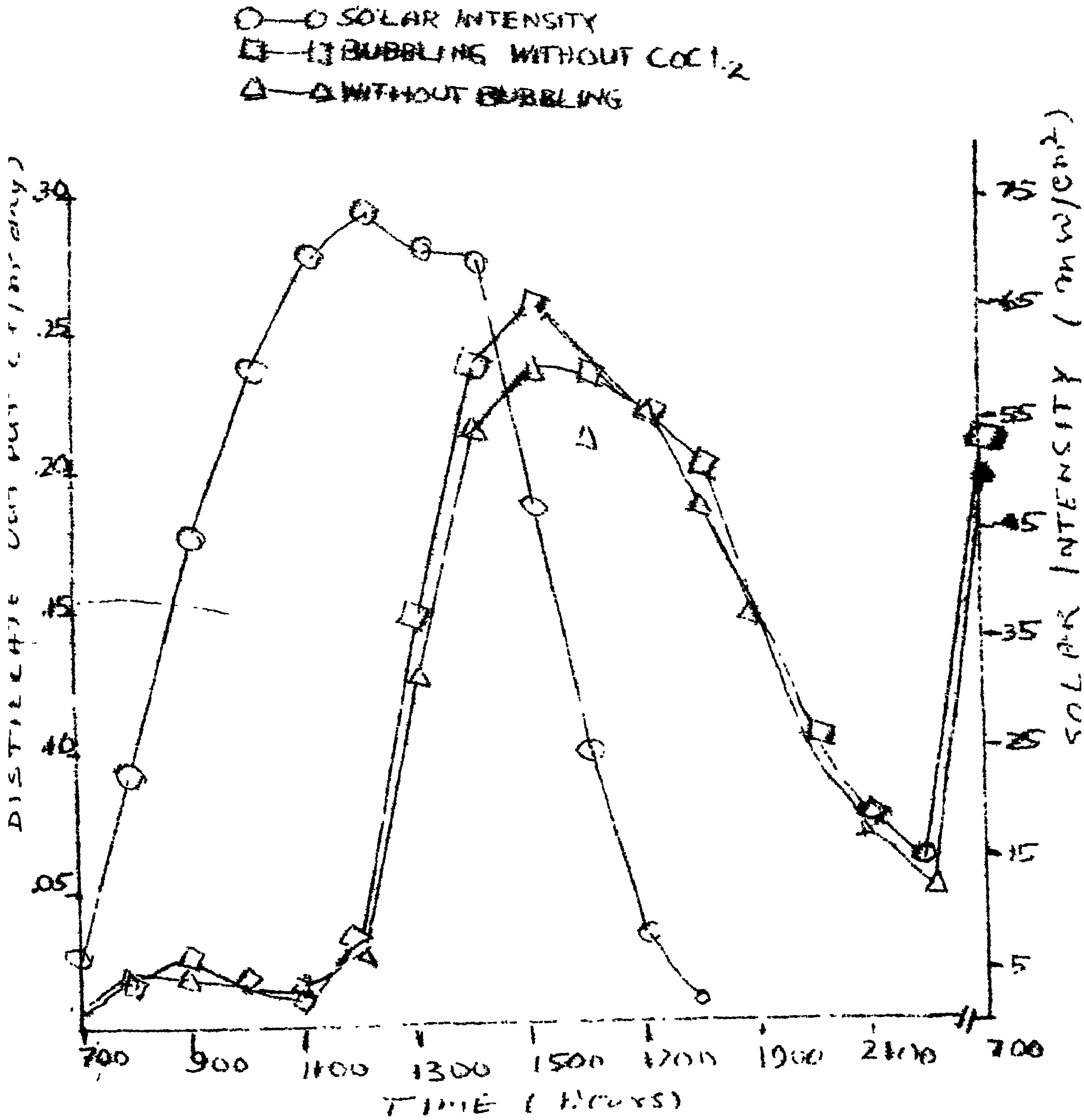


Fig V·3 Time V/S Distillate Output
(Bubbling without CaCl2)
(Ambient air)

ambient air, as expected, was lower. This is further supported from the ambient temperature data (Table V.I). Such a performance could be explained on the basis that, the capacity to absorb water (when bubbled) by humid air during the bubbling is much less compared to that by dry air. This experiment, though was not successful, provided an indication that bubbling of dry air may give a positive response. The next set of experiments was carried out with ambient air after drying i.e. by passing through a series of $CaCl_2$ traps before bubbling. As evident from the Table V.2 that as much as 33.5% overall increase in distillate output was obtained in this case. The performance data plotted in figure V.4 showed that right from morning, hourly distillate output in the experimental still had been higher than that in the reference. This experiment apart from supporting the mechanism suggested above to explain the still performance in

case of bubbling of humid air also provided an indication that such a process may also be effective even in the absense of solar energy, i.e., bubbling of dry air may be used as a method for nocturnal distillation of saline/raw water. The drying/heating of air could be achieved by solar or for that matter, any source of thermal energy (e.g., waste industrial heat). Such a method, therefore, needs a detailed study both theoretical and technological.

Table-V.2

Distillate output of Solar Still with Bubbling of Dry Ambient Air (Water Depth 4 cm)

Date & time of observation IST Hours	Time of Bubbling in minutes	Distillate output in l/m² day With Bubbling	Distillate output in l/m² day Without Bubbling	Ratio	Solar Intensity in W/m²	Temperature (°C) Ambient	Temperature (°C) Water With Bubbling	Temperature (°C) Water Without Bubbling
900	0	0	0	–	–	–	–	–
1000	40	–	–	–	–	–	–	–
1100	50	.0220	.0268	0.81	73	31	41	39
1200	55	.0758	.0230	3.29	75	32.5	46	46
1300	40	.1938	.1217	1.59	70	34.6	51	51
1400	45	.2506	.1882	1.33	85	35.0	57	54
1500	45	.2812	.2318	1.21	44	36.00	57	54
1600	40	.2389	.2113	1.13	23	35.0	44	51
1700	50	.1909	.1869	1.02	4	33.0	37	46
1800	55	.2477	.1485	1.67	2	29.0	33	42
1900	55	.1093	.1037	1.05	0	27.5	32	36
2000	45	.0801	.0871	0.92	0	28.0	30	34
2100	60	.0583	.0615	0.95	0	25.0	28	32
2200	55	.0481	.0474	1.02	0	25.0	–	28
900	–	.4196	.2215	1.89	–	–	–	–
Total (24 hours)		2.216	1.659	1.335				

Average Increase = 33.5%

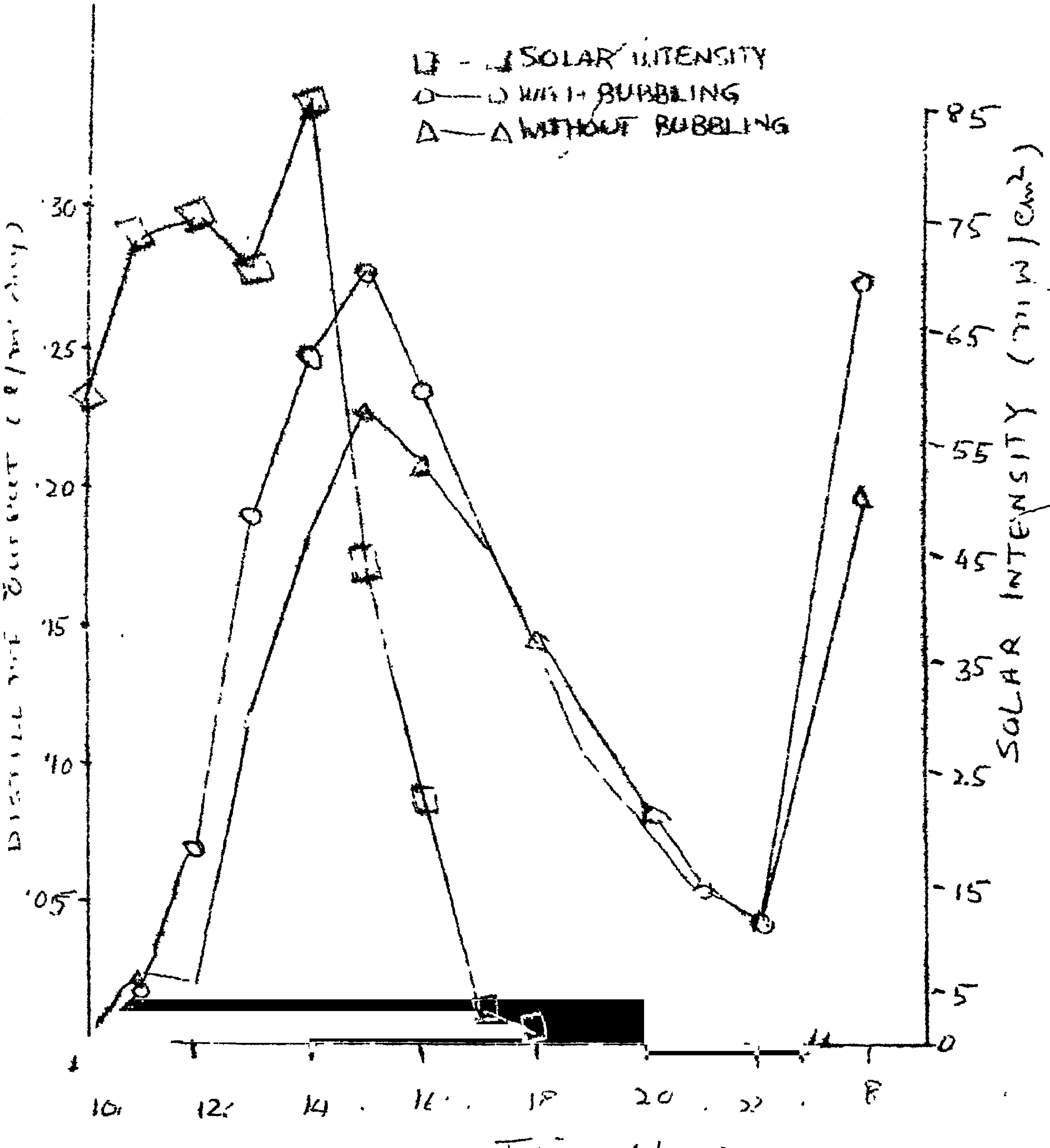


Fig V - 4 Time V/s DISTILLATE OUTPUT
(After bubbling through $CaCl_2$)

As mentioned earlier that the temperature difference $\Delta T = (T_w - T_g)$ between the glass cover and water surface also plays an important role in the distillation process in solar stills. This has now been well demonstrated, e.g., high-wind speed or cooling of glass directly increases the rate of distillation (Cooper 1973a). Having received encouraging results on the hypothesis, it was felt that simultaneous cooling of glass cover and bubbling may prove to be more effective. An experimental set up, therefore, was fabricated to study the combined effect on the performance of the still. Hourly data (Table V.3) were collected for simultaneous bubbling and cooling of glass cover. In order to correlate the performance of simultaneous bubbling and cooling, it was necessary to know the contribution of cooling of glass cover only on the distillate output. Hourly distillate output data for stills with cooling of glass cover were also collected (Table V.4). The performance of the still compared to reference for simultaneous bubbling and cooling and glass cooling alone have been shown in figure-V.5 and V.6 respectively. Data on temperature of water in experimental and reference stills and that of ambient, were also recorded and have been included in Table V.1-V.4, for different processes. An observation of these data indicated that the relative trend of water

Table-V.3

Productivity of Solar Stills with Bubbling of Dry Ambient Air and Cooling of Glass Cover

(Water Depth 4 cm)

Date & time of observation IST, Hours	Time of Bubbling in minutes	Distillate output in $1/m^2$		Ratio	Solar Intensity in W/m^2	Temperature (°C)		
		With Bubbling +Cooling	Without Bubbling +Cooling			Ambient	Water With Bubbling	Water Without Bubbling
900	0	0	0	0	0	26.0	27	27
1000	50	.0306	.0141	2.17	62	28.0	31	32
1100	45	.0838	.0179	4.96	73	30.0	35	39
1200	40	.2040	.0512	3.98	76	34.0	37	46
1300	50	.2841	.1281	2.21	70	36.0	40	51
1400	45	.2480	.1678	1.47	60	37.5	41	55
1500	50	.3610	.2215	1.63	44	37.5	40	56
1600	50	.2841	.2241	1.26	21	37.0	32	53
1700	45	.2260	.1857	1.21	6	35.0	30	50
1800	50	.1705	.1614	1.05	2	30.5	28	45
1900	50	.1297	.1409	0.92	0	26.0	27	40
2000	50	.0830	.0871	0.95	0	26.0	27	36
2100	50	.0816	.0704	1.15	0	25.0	25	34
2200	45	.0583	.0512	1.13	0	24.0	24	32
900	-	.3584	.2459	1.45	41	-	-	-
Total (24 hours)		2.608	1.767	1.475				

Average Increase = 47.5%

Table-V.4

Performance of Solar Still with Cooling of Glass Cover only (Water Depth 4 cm).

Date & Time of observation IST, Hours	Time of Bubbling in minutes	Distillate output in l/m^2		Ratio	Solar Intensity in W/m^2	Temperature (°C)		
							Water	
		With Bubbling Cooling	Without Bubbling Cooling			Ambient	With Bubbling	Without Bubbling
900	0	0	0	0	0	-	-	-
1000	[illegible]	.0699	.0102	6.85	60	25.5	27	23
1100	45	.1399	.0178	7.81	62	27.0	30	34
1200	45	.1384	.0192	7.20	63	39.0	33	41
1300	40	.1923	.0384	5.01	37	30.4	36	46
1400	55	.2083	.0996	2.09	52	30.0	38	49
1500	40	.2258	.1698	1.33	35	32.0	36	49
1600	45	.1675	.1588	1.05	18	30.3	34	48
1700	50	.1850	.1742	1.06	5	29.5	30	44
1800	45	.1282	.1076	1.19	0	26.0	32	40
1900		.3351	.5762	0.58	38	-	-	-
Total (24 hours)		1.790	1.372	1.305				

Average Increase = 30.5%

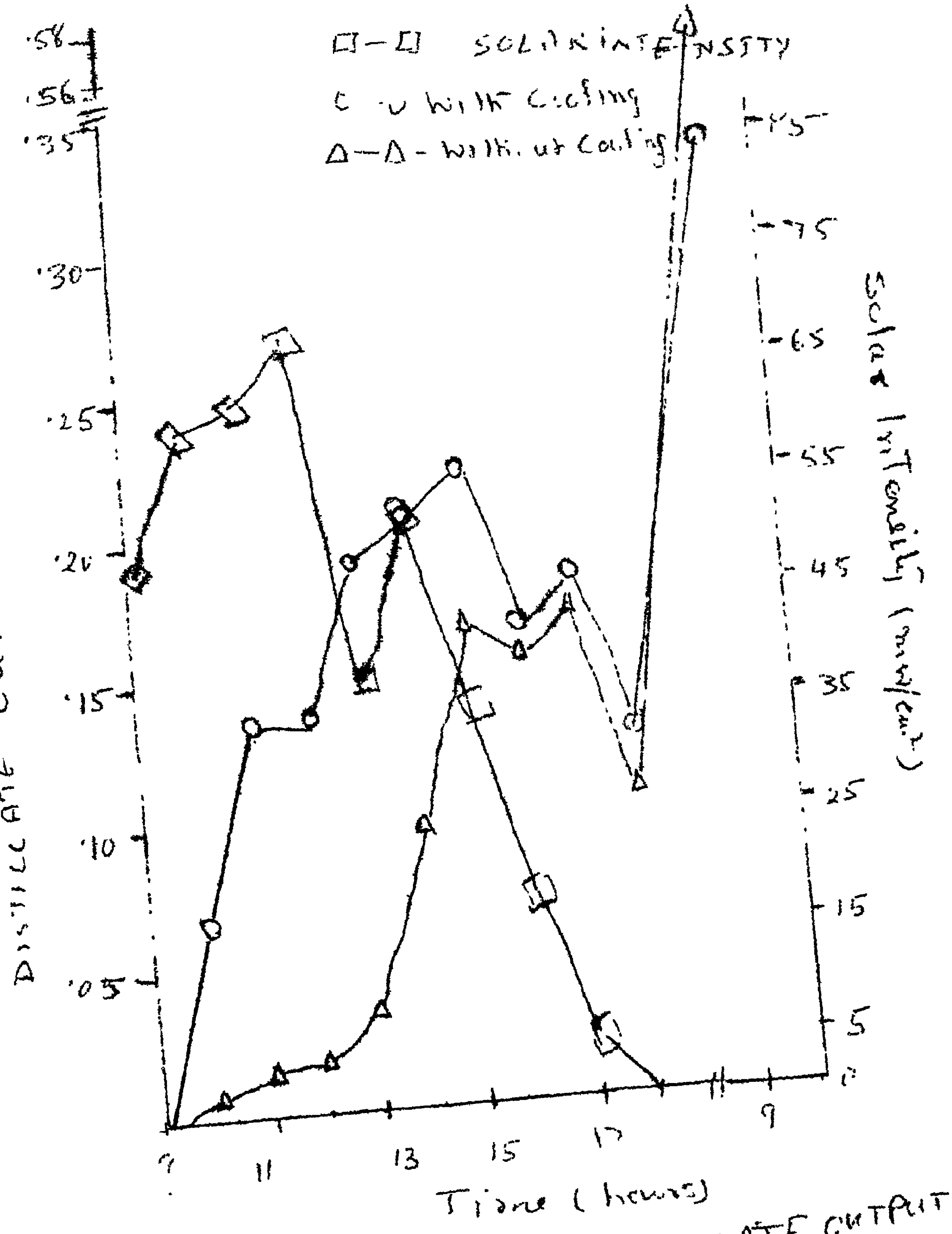


Fig V.5 Time V/s DISTILLATE OUTPUT with surface cooling (glass)

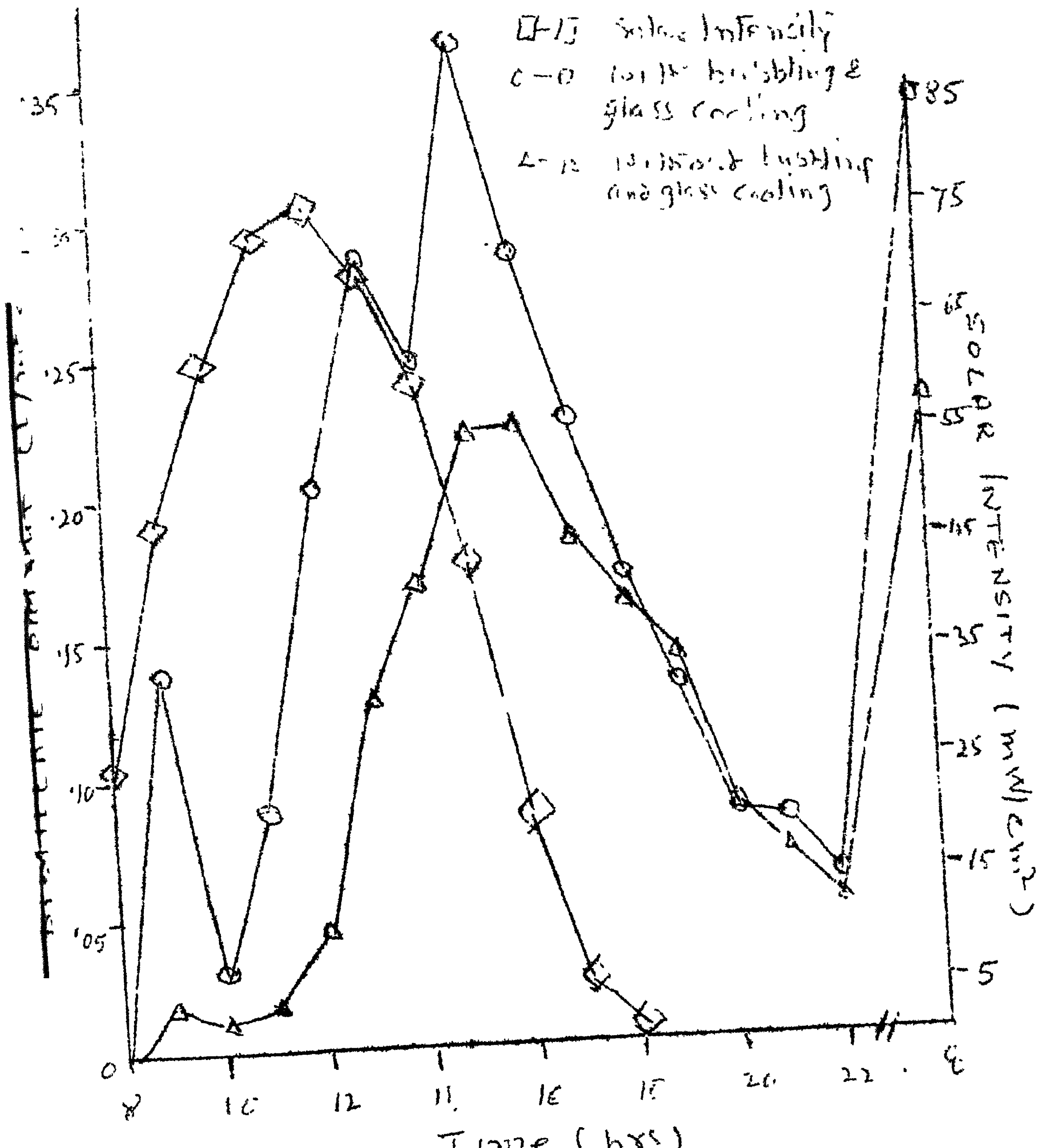


Fig V.6 Time V/S Distillate output
(With bubbling dry air and glass cooling)

temperature variation in the bubbling experiment with and without drying was same compared to reference except a slight lowering trend in the afternoons. This could be due to reduction of incident solar intensity as water with bubbling could not store thermal energy (as in the case of reference) and was dependent upon incident solar energy.

The average performance data have been given in Table-V,5, which indicates that simultaneous bubbling of dry air and glass cooling gives the highest increase followed by bubbling of dry air. It may be mentioned that the results presented here are based on preliminary work undertaken with a view to see the feasibility of such a method. A detailed study is in progress.

B. Stirring of Water

The experimental set up consisted of a long stirrer rod connected to a (mechanical) stirrer motor. The other end of the rod was placed in the water through a hole from the back side(higher wall) of the still basin. The hole was carefully covered to reduce the vapour leakage. The still was made of aluminium having a basin area of 0.25 m^2. The water depth taken was 6 cms. After the transient phase was over, hourly data were taken. The time of stirring varied from 45 minutes to 50 minutes, in an hour. The

Table-V.5

Relative Performance of Solar Still for Different Processes

Sr. No.	Process	Distillate output l/m² for 24 hours: Experimental Still	Reference Still	Ratio	Per cent Increase in distillate output
1.	Bubbling of Ambient air	1.981	1.849	1.071	7.1
2.	Bubbling of ambient air after drying	2.216	1.659	1.335	33.5
3.	Bubbling of dry ambient air + cooling of glass cover	2.608	1.767	1.475	47.5
4.	Cooling of glass cover only	1.790	1.372	1.305	30.5

experiment was repeated after a week. The extent of increase in distillate output has been compared with the performance of the reference still under similar experimental conditions.

Results and Discussions

This work was based on the principle that stirring of water within the still, increases the extent of transfer of water molecules to the air mass due to (faster) recirculation of the air/vapours enclosed within the still. Such a process disturbs the normal gas/liquid equilibrium the still. The recirculation of the enclosed air/vapour through the water is expected to saturate the air/vapour mass which is turn leads to faster condensation of vapour on the glass cover inorder to maintain the equilibrium within the still. This process, if continuous, is expected to increase the rate of distillation in the still.

Hourly data for two different sets were taken and reported in Table-V.6. The relative performance of the stillhave been shown in figure V.7. It is evident from this figure that stirring of water increases the relative productivity of the still considerably (compared to reference) during day

Table-V.6

Effect of Stirring Raw Water on Hourly Productivity of Still at 6 cm depth

Set No.	Time of Observation	Time of Stirring (within one hr.)	Output in l/m^2 day With Stirring	Output in l/m^2 day Without Stirring	Ratio	Solar Intensity in mW/cm^2	Temp. of water °C
Set I	9 AM	0	0	0	0	50	41
	10 AM	45	0	00	0	64	48
	11 AM	45	0	0	0	76	56
	12 AM	50	0.048	0.027	1.77	78	62
	1 PM	45	-	-	-	-	-
	2 PM	45	0.320	0.150	2.13	20	69
	3 PM	45	0.3252	0.173	1.45	56	66
	4 PM	45	0.184	0.148	1.24	38	64
	5 PM	45	0.180	0.181	0.99	22	58
	6 PM	45	0.136	0.148	0.91	10	53
	6 PM to 10AM	-	0.200	0.480	0.41	-	-
Set II	9 AM	0	0	0	0	58	44
	10 AM	50	0	0.009	0	72	52
	11 AM	50	0.060	0.022	2.72	96	56
	12 Noon	40	0.088	0.045	1.95	28	58
	1 PM	50	0.180	0.081	2.22	102	61
	2 PM	50	0.168	0.089	1.88	72	58
	3 PM	40	0.136	0.089	1.52	20	55
	4 PM	50	0.080	0.081	0.98	52	56
	5 PM	60	0.012	0.185	0.84	32	54
	5 PM to 9AM	-	0.100	0.388	0.25	-	-

Date of observation for Set I and II were June 16 and 24, 1980 respectively.

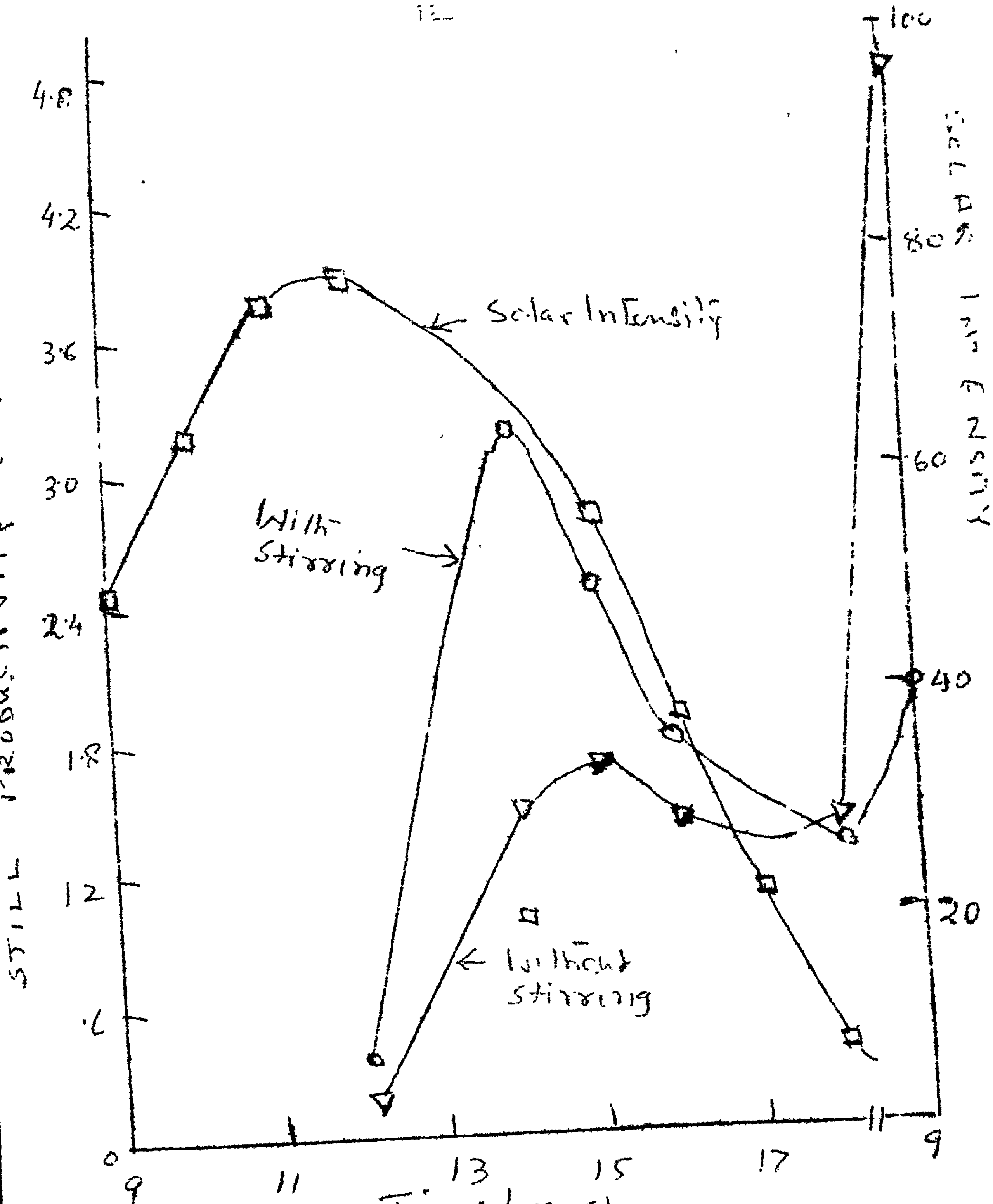


Fig V.7 Hourly Variation of still productivity with and without stirring.

time and has direct correspondence with the solar intensity (time lag being two hours). However during night the productivity of the experimental still was much less (nearly one fourth of the reference still). This behaviour can be explained on the basis that stirring does not allow storage of incident solar energy (as thermal energy) by water during day which causes distillation in the absense of sun light. However it may be pointed out that inspite of low productivity in the night, over all daily productivity (24 hours) was still higher in the experimental still.

This study thus indicates that stirring of water at lower waterdepths increases the rate of distillation It may be mentioned that only technological improvement/ development in the existing solar still will be required for operation of stirrer by wind energy.

<u>Conclusion</u>

It is evident from the forgoing discussions that the efficiency of the still can be increased to a considerable extent by providing arrangements for simultaneous dry air bubbling and glass cooling. The system however, may need a detailed technological study with aview to design a system where wind energy can

be used for bubbling (e.g., tunnelling or use of paddles to be operated by wind energy). Such a system, however, may increase the capital cost slighly.

This process has following applications:

i) Water Deslinat on in coastal area (where wind energy is in plenty):

(a) distilled water can be obtained even in the absence of solar energy;

(b) overall distillate output can be increased to some extent by distillat on of used $CaCl_2$ (in another still) in the process of recovery of $CaCl_2$.

(ii) Recovery of water from waste water: The process of transfer to water molecules from brackish water is expected to be more effective if the dry air to be bubbled is hot, leading to increased distillation rate. The heating of air, however, can be done either by waste industrial heat or solar air heaters.

(iii) Continuous stirring of water in the still is equally promising specially where wind energy can be used for stirring (running of the stirring by wind mills). Only technological developments are required.

CHAPTER-VI

EFFECT OF DYE ON THE PERFORMANCE OF A DOUBLE BASIN SOLAR STILL

Summary

The use of single basin solar stills for water distillation has been well demonstrated. However, distilled water produced per unit area is fairly low and makes it unacceptable in situations where space is a limitation. Malik (1978) suggested a new conceptual design of double basin solar still to overcome the above problem partially. Results obtained on a double basin versus single basin solar still have been reported with reference to (a) its performance, (b) the effect of dye in the lower basin, and (c) the effect of maintaining the raw water level in basins, have been reported in this chapter.

For any feasible utilization of solar energy, large areas are required for the installations. Solar distillation plants are no exceptions. It still remains a fact that fairly large areas will be needed for the solar stills to meet the potable water requirement even for domestic purposes. Mallick

(1978) suggested a conceptual design of a double basin solar still, which may solve the space problem to certain extent. This still has two basins one over the other and is expected to be more efficient due to better utilisation of thermal energy within the still. Since the working principle of the lower basin of this still was similar to that of the conventional single basin still, a study on the effect of dyes on the performance of double basin still was undertaken. The performance of this still was studied both in presence and absense of the dye (in the lower basin). The results have been discussed in this chapter.

Double Basin Still:

Because of the disadvantages of large area requirement (per unit mass of water distilled in conventional basin-type stills) different geometrical configurations for solar stills have been tried out. In single-basin-type stills, part of the solar intensity absorbed by the basin liner is used in solar disttllation while rest is lost to the surroundings (i) by conductive mode through the insulation under the basin liner and (ii) by convective and radiative modes through the upper glass cover.

The losses through the insulation, however, can be minimised using good insulating material. With a view to minimizing the convective and radiative losses a double-basin-type-still has been fabricated. It differs from conventional

roof-type-still in having another transparent sheet of material (Glass is preferred for reasons known quite well) fixed in between the basin liner and glass cover; this sheet serves as the base of an extra basin for saline water. The water in the upper basin reduces solar intensity available on the basin liner, but makes use of the upward heat loss, by the water in the lower basin.

Thus in effect the whole assembly behaves as two single basin stills kept one above another and as a result it has a smaller area requirement per unit mass distilled in comparison with the conventional still.

Experimental

The double basin solar still was made of G.I. sheet (20 gauze) having basin dimensions 0.9 m x 0.8 m and the vertical heights being 0.35 m and 0.54 m on the lower and heights of the lower basins were 0.19 m and 0.28 m. The glass cover from the horizontal surface were 7° and 10° in the lower and upper basins respectively. The thickness of the glass cover was 4mm. The assembly as shown in figure VI.1, was made air tight. Aluminium drains were provided in each basin for the collection of distillate. A single basin still having similar dimensions (except the glass in the middle) was used for comparison.

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higher sides respectively. The vertical

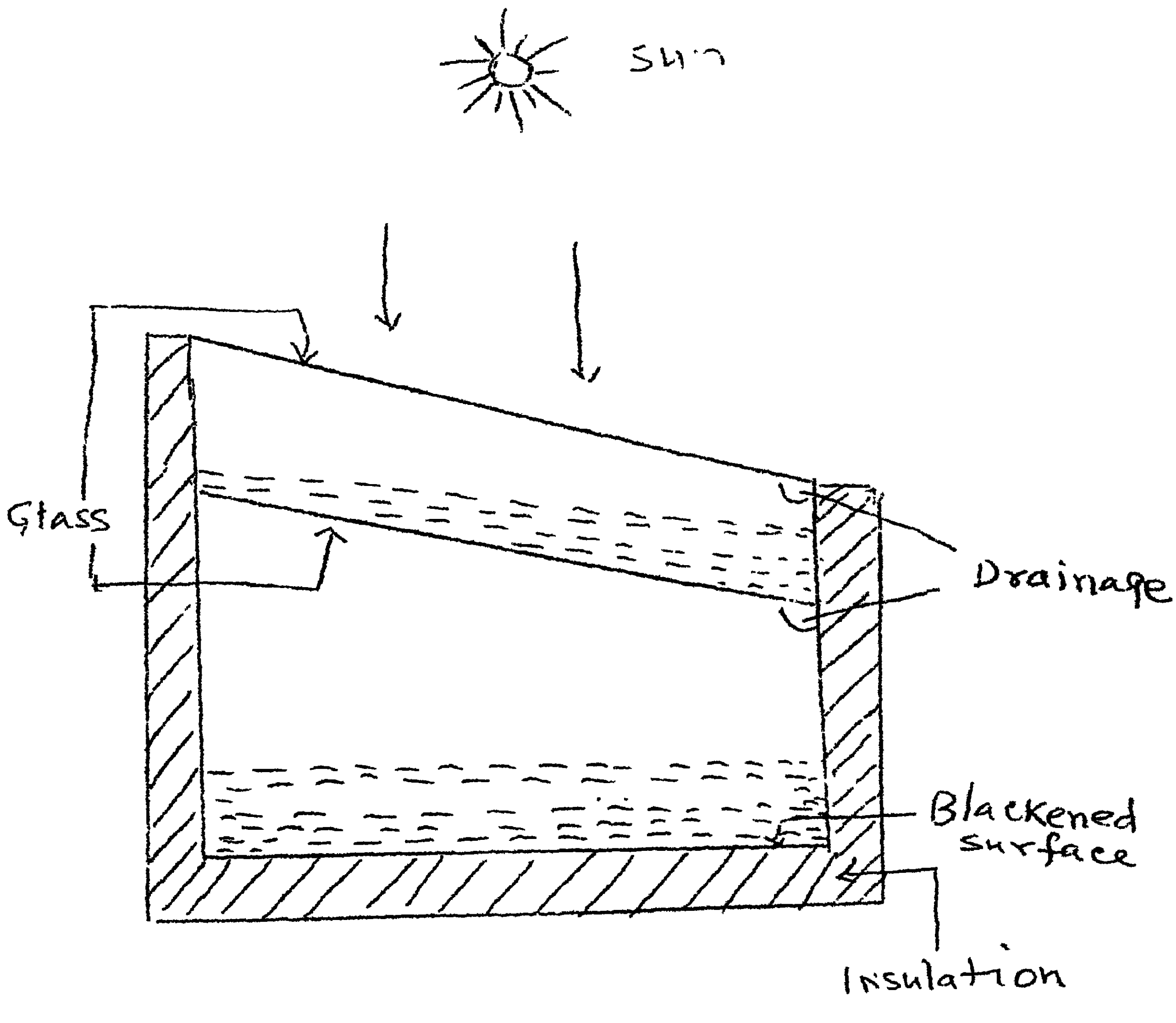

Fig VI.1 Double Basin Solar Still

The water levels in the lower basin and the reference were kept same. The water in the upper basin, however, was kept at 1 cm. i.e. enough to keep the glass surface covered with the water on the higher side.

The data were collected after the transient phase was over. The data on distillate output, temperatures of water, glass and that of the atmosphere were also recorded daily. A few sets of data were also taken on hourly basis.

Results and Discussions

Cooper (1972) reported that 2-6% of solar radiations reaching water surface in a conventional type single basin still are directly reflected back by the clear water, about 30% is absorbed by it and rest is transmitted to the black bottom of which a major portion is lost. The conceptual design of Malick seems to be more advantageous over the conventional design in the sense that:

(i) The effect of surface area required per unit volume ofwater produced from the solar stills is reduced;

(ii) the latent heat released, on the glass cover of the lower basin, during condensation of water vapours into liquid water, is transferred to the water mass, above the glass surface which, in turn, is used to heat it and;

(iii) the thermal losses by way of radiation and convection in the lower basin are reduced due to insulation(water mass) on the glass cover.

It may be mentioned that due to two basins, the extent of solar radiations reaching the black bottom of the lower basin is reduced, but as already mentioned, the overall energy utilization is increased. One of the ways of increase the absorption of incident solar energy, as demonstrated by the author (Pandey 1981), is by mixing the raw water with a suitable dye. This raw water then acts as a liquid collector and is expected to increase the solar energy absorption.

To obtain a comparative data following sets of experiments were carried out:

(a) The performance of double basin still containing water only was studied with reference to a single basin still having similar dimensions.

(b) The dye was mixed with the raw water in the lower basin, keeping plain water in the upper basin. The performance was studied with reference to single basin still containing plain water;

(c) The performance as in set (b) was studied while the water levels in both the double basin and reference stills were maintained.

Hourly data on distillate output for set (a) have been given in Table VI.1 and the performance of the still has been shown in figure -VI.2. These data indicate that the double basin still gives about 45% higher yield per day compared to basin reference. This behaviour is in accordance with the expected trend because of the fact that (i) double basin still functions as two stills (ii) the upper basin has smaller water mass and (iii) the water mass (in the upper basin) gets additional thermal energy due to transfer of latent heat of condensation at the glass cover of the lower basin. An observation of figure-VI.2, indicates that the rate of distillation remained same in both double and reference stills during the day where as as much as 88% more distillate output is obtained in the double still compared to reference during night. This behaviour can best be explained on the basis that during night, the ambient temperature goes down which, in turn, increases the rate of distillation in a single basin still due to high $\Delta T (= T_w - T_g)$. This leads to faster cooling of the water mass in the basin. In double still, on the other hand, the heat transfer mechanism is somewhat different viz. the cooling of water mass in the lower basin is slow due to lower ΔT, value (compared to reference) and hence the rate of evaporation is expected to be slow but continues for a longer period. This, in turn, becomes a continuous source of thermal energy to the water mass in the upper basin. This also

TABLE VI 1

[illegible] Spin:

Date/ [illegible]	[illegible]	P[illegible] (1/ 2 [illegible])x 10-[illegible]			S[illegible]	[illegible]/[illegible]	[illegible] (-/c)
	[illegible]	[illegible] basin [illegible]		[illegible]			
Set I							
.6.61							
10.0[illegible]	[illegible].1	[illegible]	1.[illegible]	[illegible].7	[illegible]	6[illegible]
11.0	5.2	7.[illegible]	[illegible]	[illegible].4	[illegible]	[illegible]
12.00	7.0	9.1	[illegible]	[illegible].1	1.[illegible]	[illegible]2
1[illegible].00	[illegible]	20.0	1.[illegible]	1.0	[illegible]	[illegible]
14.00	26.0	[illegible].1	20.0	[illegible].1	[illegible]	7
15.00	5.0	[illegible].7	22.5	[illegible].2	[illegible]	[illegible]2
1[illegible].0[illegible]	[illegible]	27.0	[illegible]	[illegible]	1.[illegible]	[illegible]
17.00	32.0	2[illegible].0	1[illegible]	[illegible].0	1.[illegible]	1[illegible]
[illegible]00	1[illegible]1.0	21[illegible].0	126.0	[illegible].0	1.[illegible]	7
T[illegible] (2[illegible] [illegible]).	[illegible]12.[illegible]	[illegible].9	139.9	50[illegible]	1.[illegible]	
Set II						
[illegible].5.61	347.0	60.0	12[illegible]	[illegible].0	1.[illegible]	
[illegible].6.61	[illegible]	[illegible]2[illegible].0	1[illegible].0	[illegible].0	1.[illegible]	
[illegible].6.61	[illegible]20.0	[illegible]	1[illegible].0	[illegible].0	1.5[illegible]	
[illegible].6.61	[illegible]16.0	[illegible]2.0	1[illegible].0	[illegible]65.0	1.[illegible]7	
7.6.61	[illegible].0	2[illegible].0	[illegible].0	[illegible]24.0	1.[illegible]5	
[illegible].6.61	[illegible]5[illegible].0	[illegible]7.0	13[illegible].0	[illegible].0	1.[illegible]7	
[illegible].6.61	[illegible]5[illegible].0	[illegible]2.0	1[illegible]	[illegible]89.0	1.[illegible]	
10.6.61	[illegible].0	[illegible]57.0	1[illegible]	[illegible]0[illegible]	1.[illegible]1	
11.6.61	[illegible]71.0	[illegible]61.0	17[illegible]	[illegible]	1.[illegible]	

[illegible] = [illegible]

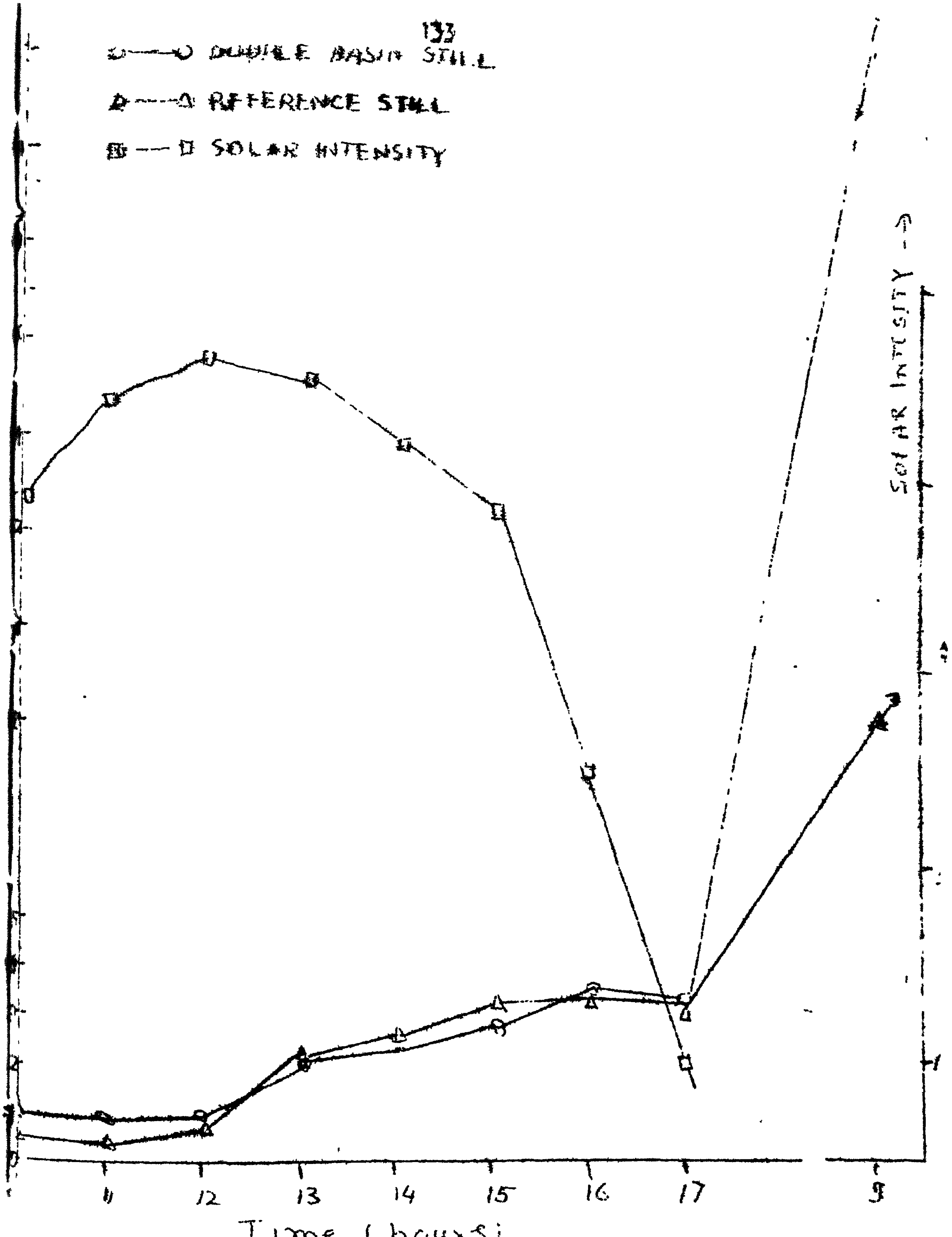

Fig VI. 2 Hourly variation in output in Double Basin Still.

support the observation that distilled water is also produced from the upper basin during night even though there is no heat storage. The mechanism suggested also accounts for the fact that the distilled water produced during night is much higher (almost double) than that produced during the day.

An observation of the black bottom of the double still indicates that its solar collector efficiency is expected to be much lower than that of the reference due to one additional glass and 1-2 cm water mass. In an attempt to improve the collector efficiency the raw water in the lower basin was mixed with a dye based on the experience of our work on liquid collector efficiency of dye mixed raw water on the performance of the sigle basin still (Pandey 1981 b). Two dyes namely Diphenyl Black and methylene Blue were studied. The performance data have been given in Table-VI.2, for black and Table VI.3 for blue dyes. The data indicate that the extent of increase in distillate output due to presence of dye is not same as that observed in a single basin still for obvious reasons. However, the hourly data (Table-VI.2) for black dye supports the mechanism suggested earlier i.e., the rate of distillation during night rose from 88% (figure VI 2, without dye) to 203% (figure.VI.3 with dye). In other words this shows that the stored energy does play an important role in the performance of the double basin still.

Table- VI.2

Hourly and Daily Productivity of Double Basin Solar Still, with Black Dye in Lower Basin (100 ppm).

Date & time of observation	Productivity of Still in l/m^2 day X 10^{-2}				Ratio D/A	Solar Intensity (mW/cm^2)
	Reference Single Basin Still A	Double Basin Still				
		Upper Basin B	Lower Basin C	Total Output D=B+C		
Set I 23.6.81						
1000	2.3	7.0	1.4	8.4	3.65	64
1100	3.5	10.0	0.6	10.6	3.02	78
1200	10.0	15.0	-	15.0	1.50	86
1300	-	-	-	-	-	-
1400	43.0	39.0	3.2	42.2	0.98	20
1500	41.0	32.0	6.0	38.0	0.92	56
1600	34.0	28.0	7.0	35.0	1.03	38
1700	35.0	30.0	10.0	40.0	1.14	22
1800	36.0	28.0	12.0	40.0	1.11	10
900	132.0	161.0	107.0	268.0	2.03	48
Total (24 hours)	336.8	350.0	147.2	497.2	1.47	
Set II 24.6.81	313	308	183	491	1.56	
25.6.81	291	317	127	444	1.52	
26.6.81	279	272	113	385	1.38	
27.6.81	172	158	78	236	1.37	
28.6.81	229	233	97	330	1.00*	
29.6.81	316	315	144	359	1.45	
30.6.81	204	211	103	314	1.54	

Average Increase = 17%

* This data is not included in calculation

Table-VI.3

Distillate output in double basin still in presence of Methylene Blue.

Date of observation	Productivity in l/m^2 day				Ratio A+B/Ref.
	Reference Still (Single basin)	Double Basin Still			
		Upper Basin A	Lower Basin B	Total (A+B)	
31.10.81	1.53	1.65	0.74	2.39	1.56
1.11.81	1.54	1.62	0.78	2.41	1.56
2.11.81	0.99	1.25	0.43	1.68	1.73
3.11.81	0.96	1.03	0.51	1.54	1.60
4.11.81	1.11	1.17	0.64	1.81	1.63
5.11.81	1.25	1.04	0.68	1.72	1.37

Average Increase = 57.5%

* The concentration of the dye and water depth in the lower basin was 100 ppm and 6 cm respectively.

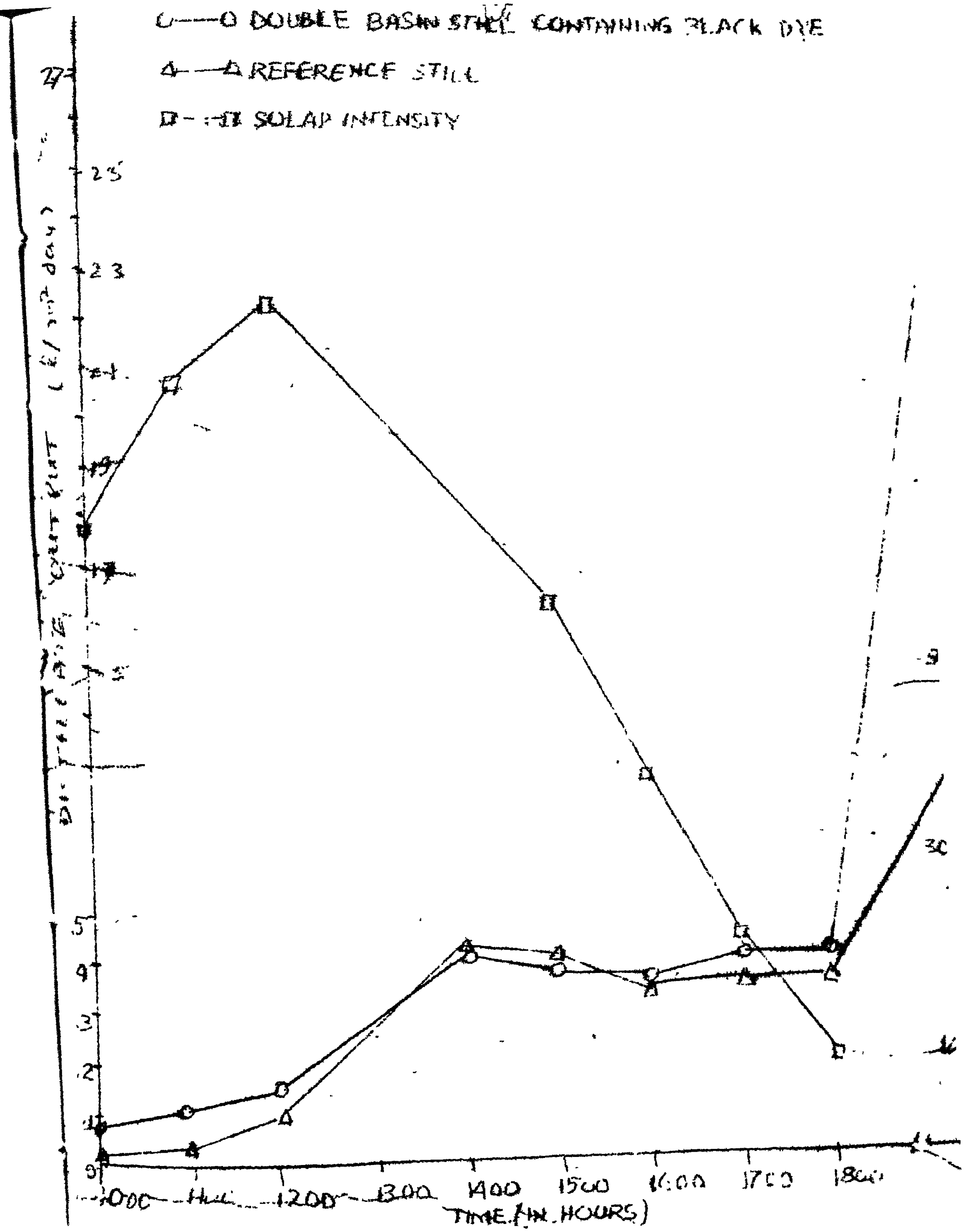

Fig VI.3 EFFECT OF BLACK DYE ... HOURLY PERFORMANCE OF DOUBLE BASIN ST...

A similar behaviour has also been observed for the blue dye as is evident from the data of Table-VI.3. The additional increase due to this dye only was found to be around 11% whereas the corresponding figure for the single basin having similar dimension and during the same period was around 16% (Table-VI.4). This thus leads to conclusion that the presence of dye enhances the rate of distillation.

During the course of the work it was observed that the raw water in the upper basin used to exhaust quickly (due to smaller water mass). An experiment, therefore, was carried out to see the effect of maintaining the (raw) water level in the still basins. This was done with the help of water level maintainer. The distillate output data reported in Table-VI.5, indicate that the maintenance of water level does not show any positive effect. However, it is recommended that the water level should be maintained in the upper basin

<u>CONCLUSION</u>

1. Single basin still are better both in terms of capital and maintenance cost. However in situations where space is a limitation, double basin stills will be most suitable in view of the fact that same basin are as capable of providing 50%-60% more of distilled water.

2. The extent of thermal energy utilization is much higher in double basin still, i.e. they are more efficient.

3. The presence of a dye in the lower basin of the double basin still increases the overall distillate output and needs a detailed study.

Table-VI.4

Performance of Methylene blue in single basin still*.

Date of observation	Productivity in l/m^2 day With Dye	Without Dye	Ratio
31.10.81	1.37	1.24	1.10
1.11.81	1.44	1.25	1.15
2.11.81	1.00	0.79	1.27
3.11.81	0.90	0.77	1.16
4.11.81	1.03	0.90	1.14
5.11.81	1.17	1.01	1.15

Average increase = 16.2%

*This experiment was done on a still similar in size etc. to that of the double basin still. The dye concentration and water depth was 100 ppm and 6 cm respectively.

CHAPTER-VII

THERMAL STORAGE AND WATER QUALITY

Summary

The dye mixed brackish water at higher (water) depths increases the distillate output compared to reference, both during the day and night. The distillation in the absence of incident solar radiation (night) has been attributed to be due to the thermal energy stored by the dye containing brackish water during the day. Possible utilization of this stored thermal energy for other low temperature applications have been discussed.

The water quality studies were also done. It was found that the distilled water is comparable with that obtained by any other standard method. The water did not contain even traces of the dye used in the still.

A. Thermal Storage in Solar Stills

It has been shown earlier that use of dye in solar stills increases the distillate output due to increased absorption of incident solar radiations and reduced reflection losses i.e. (liquid) collector efficiency of the still is increased. The collector property of the water is due to its fundamental characterstic property viz. high heat capacity (= 62 BTU/ ft^3 °F), which allows the storage of thermal energy by water as well as reduction in thermal losses in the still.

While the dye mixed water increases the absorption of incident sun light in the vissible region, an increase in the water mass provides thermal storage in the still. This stored thermal energy in the still is responsible for nocturnal distillation. (i.e. in the nights). This has experimentally been observed during the course of the work on dyes. Continuous (morning 10 a.m. and evening 5 p.m.) data collection for about a week was done in November 1980. Distillate output data of the still containing Mathylene Blue and that of the reference have been reported in Table VII.1. The data of 10 a.m. and 5 p.m. correspond to the productivity during the night and the day respectively. It is evident from the Table that the extent of increase in productivity of the still containing dye was much higher in the nights. The daily performance was variable (due to difference in the weather conditions). Relatively higher increase in distillate output during night can be

TABLE- VII 1

Thermal Storage and Productivity of the Solar Still in presence of Methylene Blue

S.No.	Date & time of observation (Day/Night)	Distillate output (l/m^2 day) With dye	Without dye	Ratio Day	Night	Percent increase Day	Night
November, 1980.							
1.	8(Night) *	0.00	0.00	0.0	--	--	--
2.	--(Day) *	0.90	0.77	1.169			16.9
3.	9(Night)	0.63	0.44		1.430		43.0
4.	--,(Day)	0.38	0.35	1.086		8.6	
5.	10(Night)	0.33	0.23		1.435		43.5
6.	--,(Day)	0.90	0.77	1.169		16.9	
7.	11(Night)	0.58	0.38		1.526		52.6
8.	--,(Day)	0.58	0.48	1.208		20.8	
9.	12(Night)	0.46	0.32		1.438		43.8
10.	--,(Day)	0.94	0.84	1.119		11.9	
11.	13(Night)	0.46	0.38		1.211		21.1
12.	--,(Day)	0.94	0.84	1.119		11.	
13.	14(Night)	0.50	0.38		1.316		31.6

* These correspond to the data collected at 5 P.M. and 10A.M. the next day respectively.

explained on the basis that a major portion of the incident energy absorbed by the dye mixed water is stored during the day and utilised for nocturnal distillation in the night. This is further evidenced by the increased temperature difference between the water and glass cover. The data reported are on a small still. It is expected that a detailed study on bigger stills (involving large water mass) may turn out to be more efficient storage system and the stored energy could also be utilised for other low temperature applications (Pandey, et. al., 1983).

B. Water Quality of the Distilled Water

During the course of this work doubts regarding possible transfer of the dye to the distilled water during solar evaporation in the still containing water soluble dye, were raised. The dye if transferred was expected to contaminate the distillated water. In order to ensure this important aspect the distillate output was analysed and the results obtained have been given below:

1. Physical Properties: The water was clear and free from any turbid material. The pH was found to be 7.0 ± 0.3, indicating that the water was almost neutral. The conductivity of the water was also found to be very low.

This shows the absence of any ionic constituent in the water.

2. Chemical Properties: The water was analysed for possible

chemical/ionic content by standard chemical method (A.P.H.1975) and/or atomic absorption spectrometry. The concentrations of the ions commonly found in the water like Ca^{+2}, Mg^{+2}, Na^{+}, Cl^{-}, $SO_4^{=}$, $CO_3^{=}$ and NCo_3^{-} were found to be in negligible quantities.

3. Spectroscopy : The presence of dye in distilled water was examined by one of the most sensitive technique spectrophotometry. Transmission spectra of the representative distilled water samples were recorded on Hitachi Spectrophotometer and reproduced in figure VII.1. The spectra of the dilute aquous solutions of the dyes used in the stills were also recorded and shown in the above figure. An examination of these spectra indicates that the spectra of the distilled water obtained from the stills, containing different dyes were reimposable and did not show the contribution of the dye even in trace quantities (the absorption spectra in the vissible region did not show any absorption).

It may be worth mentioning that Rajvanshi (1981) and Venkatraman et. al.(1982) have also reported that the distilled water obtained from the stills using water soluble dyes, were comparable with that obtained by any other standard method and did not contain even trace of the dye used in the still for distillation.

The above results thus show that the use of the dye in the still does not affect the quality of the distilled water. The water, therefore, can safely be used for drinking purposes.

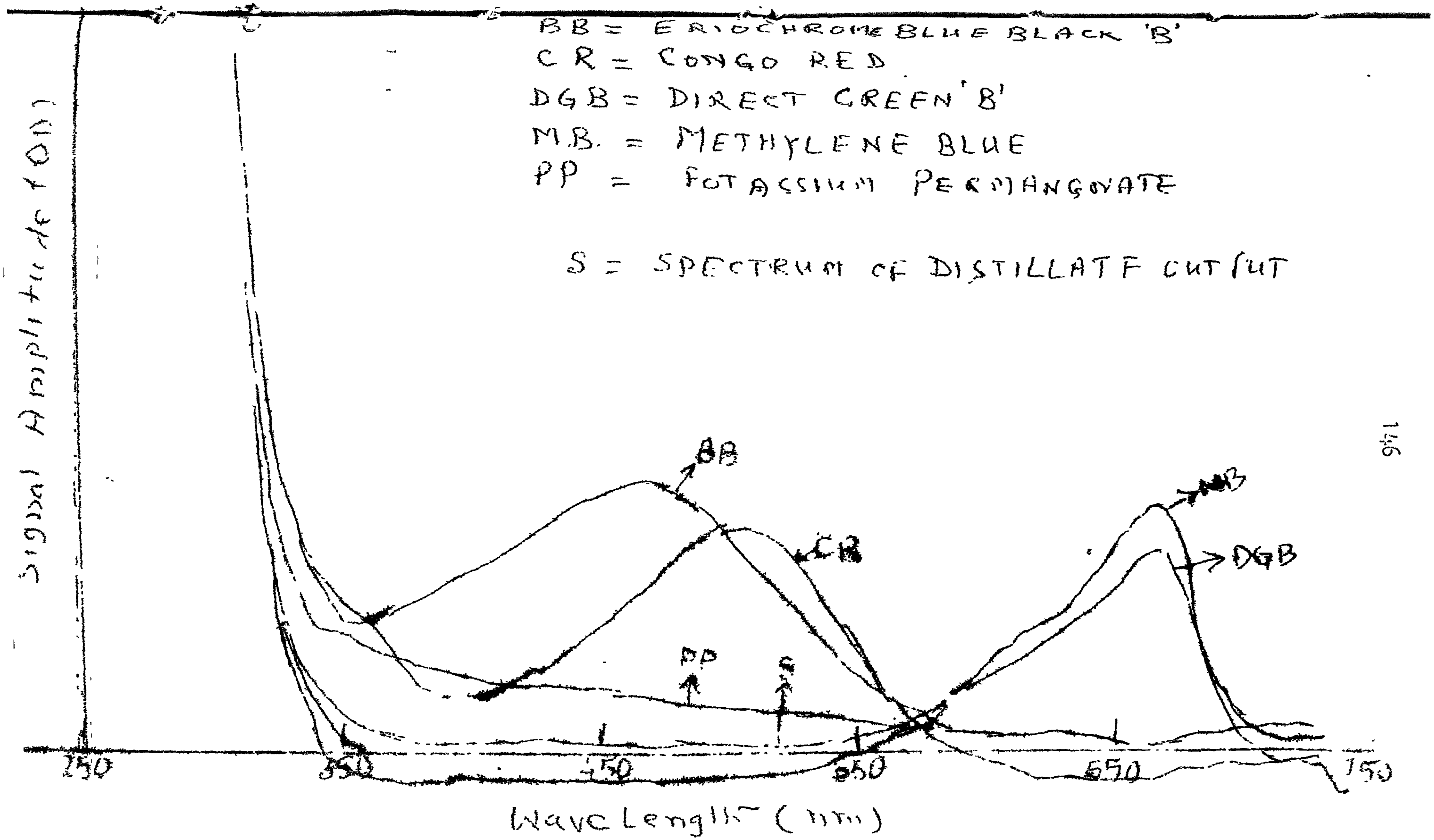

Fig VII 1 TRANSMISSION SPECTRA OF AQUEOUS SOLUTIONS OF DYE AND DISTILLED WATER FROM STILL.

RECOMMENDATIONS

1. Studies on large solar distillation plants (field trials) both with plain and saline water should be undertaken with special reference to:

   (a) the extent of increase in distillate output,

   (b) the stability of the dye (active half life of the dye), and

   (c) the savings achieved by use of dye vis-a-vis the cost of black painting, manpower and savings due to continuous operation of the still (which is not so in case of black bottom painted still - as salt cleaning is required at certain intervals).

2. A detailed study on inorganic dyes should be undertaken both in plain and saline water.

3. Seasonal performance of the stills containing dye should be undertaken on large stills to obtain average (annual) percent increase in distillate output. This will provide a basis for-

   (a) determination of size of the distillation plant in the light of water requirement,

   (b) economics of the distillation process using dyes.

4. Work on floating coal and colonization of water in the still* (surface area study) should be extended on large stills (field trials).

5. A detailed study on effect of dried and forced air bubbling on the water vapour pressure should be taken up. This is an important aspect because of its applied value, eg., this method can be used for recovery of distilled water from (nocturnal distillation) the waste hot water or the waste water.

   Studies on the engineering aspect of air bubbling without any external source of energy should also be carried out.

6. The effect of dye on the performance of double basin stills needs a detailed study.

7. The thermal storage by dye containing brackish water needs a more detailed study specially on large distillation plants (both distillation and desalination), ie., field trials.

8. In view of the lower efficiency of solar appliance, the approach of integrated use of solar stills, for instance, simultaneous production of distilled water and electrical energy (storage) as reported by the author (Pandey 1980 b, 1982 d, Pandey & Swami 1980 and Pandey & Mathur 1983 c) should be given a serious thought.

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